PROGRAMMERS MANUAL

FOR

GODDARD ORBIT DETERMINATION PROGRAM

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* Following page 57 are detailed descriptions of subroutines on pages 1-1 through 105-1.

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1.0 Introduction

This manual provides programming information applicable to the Goddard Orbit Determination Program, Phase II. It should be useful both to the programmer who may wish to modify the program and to the user who may be interested in details within the various subroutines employed.

Since the program is coded entirely in FORTRAN IV, the listings provide easily decipherable information. This manual supplements the listings by providing definitions of terms in COMMON and terms found only within a subroutine as well as detailed flow diagrams of each subroutine.

This manual is organized in the following manner:

In Section 2., a brief general description of the operational sub-programs which make up the complete Orbit Determination and Trajectory Generation Program is given.

In Section 3., a system description of the over-all program flow in the minimum variance method is provided. Details of matrix manipulation are given for cases of particular importance. A generalized flow diagram showing the interaction of the MAIN, SUMARY and EXEC subroutines with the STAT subroutine are included in this section.

In Section 4., a system description of the over-all program flow in the Bayes estimation method is provided. Details of tape formats and methods of matrix manipulation are given for cases of particular importance. A generalized flow diagram showing the interaction of the MAIN, SUMARY and the EXEC subroutines with the BAYES subroutine are included in this section.

In Section 5., lists of COMMON symbols and their definitions are given. These lists apply to each of the three sub-programs; EXECA, EXECB1, and EXECB2.

Section 6. provides descriptions of each of the subroutines in the program along with applicable flow diagrams. Because of the similarity of many of the routines, references to related routines are used extensively to avoid repitition. When applicable, the subroutine description refers to the Analytical Manual (Ref. 1) which describes the equations used in the subroutine. When equations are not provided by the Analytical Manual, they are supplied herein.

Finally, Section 7. lists the References used.

This manual was prepared under Contract NAS 5-3509 for the Theoretical Division (Special Projects Branch) of the Goddard Space Flight Center, Greenbelt, Maryland.

2.0 General Program Description

The program is divided into four separate sub-programs:

1. EXECA - Generates trajectory information only using either Cowell's or Encke's method.
2. EXECB1 - Generates statistical information using either Cowell's or Encke's method for the trajectory and Bayes Estimation or Minimum Variance for the statistical filter processing. This program considers only the six variables describing the vehicle's position and velocity as states to be statistically determined.
3. EXECB2 (A) - Generates statistical information using either Cowell's or Encke's method for the trajectory and minimum variance for the statistical processing. This program considers not only the six variables describing the vehicle's position and velocity as states but also up to 20 additional states can be selected from a number of variables such as station locations, gravitational parameters, and the velocity of light.
4. EXECB2 (B) - Same as EXECB2 (A) except that the statistical formulation is by Bayes Estimation rather than Minimum Variance. Sub-programs 3 and 4 can be combined to be equivalent to the form of EXECB1. However, storage limitations of version 9 of IBSYS makes this mode impractical. Versions 12 and 13 of IBSYS, with several hundred fewer locations required by the system, will

perhaps make this a feasible mode of operation. Similarly, B2MAIN can be written in subroutine form so that when one type of statistics is being employed, the part of MAIN corresponding to the second statistical method can be made a dummy, thereby making the composite program small enough to fit into version 9. It is not likely that any great advantage can be achieved by utilizing this mode of operation.

The general structure of these programs, their operation under "stand alone" systems and a recommended approach to their operation under D.C.S. is given in Reference 2.

3.0 Program Description, Minimum Variance Method

The main flow of statistical filtering using the Minimum Variance Method is mechanized in this program by the MAIN and STAT subroutines. Because of the similarity in the B1 (minimum states) and B2 (variable states) programs, the use of MAIN and STAT in the following discussion will imply either the B1 or B2 versions of the subroutines. Differences in the two versions will be indicated where they exist.

3.1 Minimum Variance Statistics, General Procedures

3.1.1 Modes

3.1.1.1 Mode Functions

There are six "modes" of operation available selectable by the user. A description of each mode in the program follows:

1. Process Real Data

   The data tape is read, data elimination on the basis of input criteria is established by the sub-section of MAIN called "record" and the remaining points are processed. A summary is given, if requested by the user.

2. Process Synthetic Data

   A data tape, containing no error, is written by the EXECA (trajectory generation) program. This tape is read as in Mode 1, but noise from a random noise generator (subroutine FLORNG) is added.

3. Error Analysis

   A data tape is generated in EXECA as described for mode 2. However, when it is read by this mode the program assumes that the residual is zero; that is, it is assumed that no measurement error exists. The remaining action of the program is as in modes 1 and 2, above. The covariance matrix is propagated between data points. It is modified to reflect the inclusion of information at a data point exactly as if real data were being processed, with the exception that the residual is zero.

4. Data Scan

   The data tape is read exactly as in modes 1, 2, and 3 above. However, no matrix manipulation is involved since the only desired output is that from the SUMARY routine. The difference between the measured and estimated (computed) values of an observation type is the primary output.

5. Propagation of Error

Data is not used in this mode. The input state covariance matrix is propagated to future times, and is printed at these times, to indicate the growth of the matrix.

6. Miss Coefficients

This mode is similar to mode 5 except that an offset in the states at the initial time is propagated to future times and printed to indicate the growth of error.

3.1.1.2 Matrix Flow

The matrix flow involved in the above modes will be described in this section:

A. Input/Output

Either the P matrix (covariance of position and velocity states) or the Q matrix (covariance of alpha-parameter states) can be inputted. The program computes in the alpha-states so conversions may be required. In INPUT, if P is the inputted quantity, the following conversion is made

$$Q(t_0) = S^{-1}(t_0) \; P(t_0) \; S^{-1^T}(t_0) .$$

In the output, if the P matrix is needed, the following conversion is made:

$$P(t) = S(t) \; Q(t) \; S^T(t) .$$

B. Input/Output (mode 6)

In mode 6, the input/output is the deviation between off-nominal and nominal states and is in the position/velocity coordinate system. The units are the same as the units selected for the output of the states, themselves.

C. Program Flow, MAIN and STAT Routines (modes 1, 2, 3, 5)

Matrix flow for the standard data processing modes is given by the following steps:

Step 1: Input P_o or Q_o and convert, if needed, as described above.

(INPUT)

Step 2: Integrate and find that rectification is required at t_r

Compute $\psi(t_r, t_o)$

Rectify

Let $\Lambda(t_r, t_o) = \psi(t_r, t_o)$

(MAIN)

Step 3: Integrate from t_r to data point t_d

Compute $\psi(t_d, t_r)$

Compute $\psi(t_d, t_o) = \psi(t_d, t_r)\,\Lambda(t_r, t_o)$

(MAIN)

Step 4: Translate Q_o to $Q(t_d)$

$$Q(t_d^-) = \psi(t_d, t_o)\,Q_o\,\psi^*(t_d, t_o)$$

(STAT)

Step 5: Translate Q across a data point**

$$Q(t_d^+) = Q(t_d^-) - Q(t_d^-)\,N^*(t_d)\left[N(t_d)\,Q(t_d^-)\,N^*(t_d) + \bar{\epsilon}^2\right]^{-1} N(t_d^-)\,Q(t_d^-)$$

(STAT)

** This step is bypassed in Mode 5.

Step 6: For print-out purposes, compute $P(t_d^+)$

$$P(t_d^+) = S_{br}(t_d)\, Q(t_d^+)\, S^T(t_d)$$

(STAT)

Step 7: Integrate to subsequent point, either data, non-data rectification, or t_{max}

Rectify after data are assimilated in Step 5

Set ψ matrix to I

Integrate to next point (called t' here to indicate any one of the three conditions)

Compute $\psi(t', t_d)$

*Compute $S_{br}(t')$ — S_{br} means S matrix before rectification, i.e., all coordinates are referenced to original reference body.

Rectify at t'

*Compute $S_{ar}^{-1}(t')$ — S_{ar} means S matrix after rectification, i.e., all coordinates are referenced to new reference body.

Let $\Lambda(t', t_d) = S_{ar}^{-1}(t')\, S_{br}(t')\, \psi(t', t_d)$

(MAIN)

Step 8: Translate Q (t_d) to t'

$$Q^-(t') = \Lambda(t', t_d)\, Q^+(t_d)\, \Lambda^T(t', t_d)$$

Step 9: If translation of the Q at t_{max} back to Q at T_0 is requested, switch to mode 5.

Step 10: Print

*Only if reason for rectification is reference body change. If not, S_{ar} and S_{br}^{-1} are unit matrices.

D. Program Flow, MAIN and STAT Routines, Mode 6

Step 1: Input ΔX, deviation from nominal states

(INPUT)

Step 2: Compute $S^{-1}(t_o)$

Step 3: Integrate and find that a rectification is required at t_r

Compute $\psi(t_r, t_o)$

Rectify

Let $\Lambda(t_r, t_o) = \psi(t_r, t_o)$

(MAIN)

Step 4: Integrate from t_r to print point, t_p

Compute $\psi(t_p, t_r)$

Compute $\psi(t_p, t_o) = \psi(t_p, t_r) \Lambda(t_r, t_o)$

(MAIN)

Step 5: Convert $\psi(t_p, t_o)$ to its equivalent form in Position/Velocity coordinates, Φ

Compute $S(t_p)$

Compute $S(t_p) * \psi(t_p, t_o)$

Compute $\Phi(t_p, t_o) = [S\psi] S^{-1}(t_o)$, $S^{-1}(t_o)$ computed in Step 2

(STAT)

Step 6: Compute miss coefficients at time

$$\Delta X(t_p) = \Phi(t_p, t_o) \Delta X(t_o)$$

(STAT)

Step 7: Print ΔX (t_p)

Step 8: Repeat process for next print time

Let $t_o = t_p$

Let $\Delta x_0 = \Delta x(t_p)$

Return to Step 2 and repeat

(MAIN)

3.1.2 Timing

In Minimum Variance statistics, a recursive formulation is employed. Information about the best estimate of the trajectory is accrued as each data point is processed. This formulation allows continuous processing of data and requires no iteration. The concept of "arc length" or "batch length" does not exist as it does in the Bayes statistical method.

In this program, however, the concept of "iteration" can be employed, if needed. This has significance only when the estimate of the initial portion of the trajectory is needed with high accuracy. Figure 1 illustrates how faulty initial conditions can lead to large errors during the early part of the trajectory.

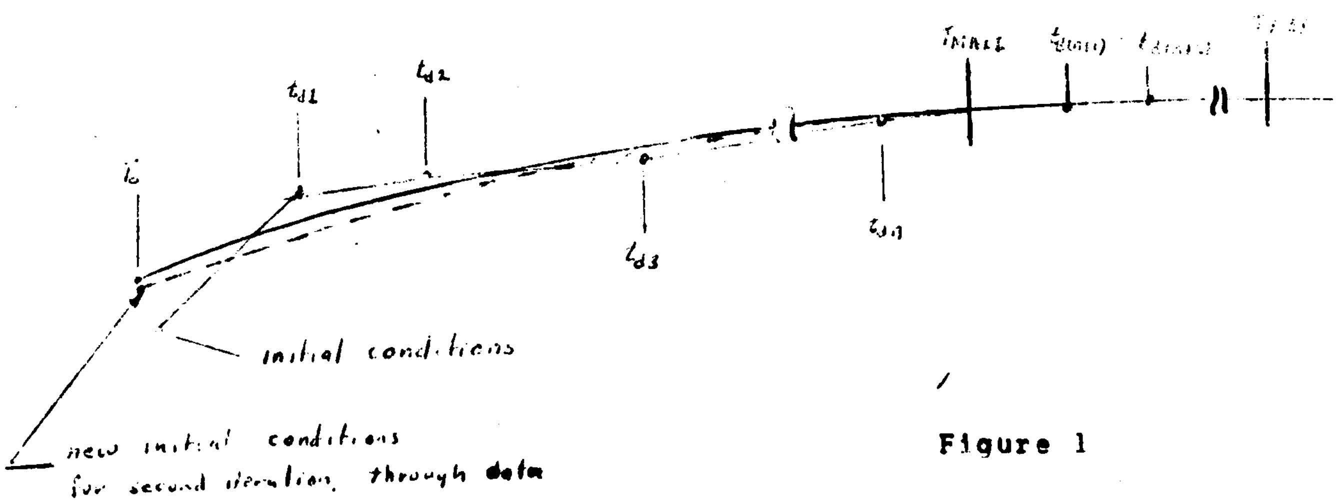


Figure 1

The program processes data to TMAX1 (solid line), can integrate back to TZERO (dashed line) and terminate at this point. The dashed line would be the best estimate of the trajectory from all of the data which had accrued through TMAX1. Since, in general, the user is interested in the best estimate of the trajectory at some time in the future, these improved initial conditions at TZERO can be used in reprocessing the data either to TMAX1 or to a later time, TMAX2.

Also, in some cases, the user might request a different program mode after the first pass through the data.

As the program time, t, completes a passage from TZERO to TMAX or from TMAX to TZERO, a counter is incremented by 1. This is called a "PASS". The number of passes is compared against an inputted maximum number of passes. When they are equal, the program tests to see if the user has requested a second run through the data with TMAX being defined as TMAX2. If it is found that this condition exists, the program is re-initialized and continues until all conditions for termination are met.

The following table illustrates the conditions for each case:

Definition	Program Symbol	Inputted Value for First TMAX	Inputted Value for Second TMAX
Max Time of Iteration	TMAX	TMAX	TMAX2
Max Number of Passes	PASF	PASFX	PASS2

The internal symbol ITER2 is set to 0 for the first TMAX and to 1 for the second TMAX.

When the program is in mode 4, or when the user requests the summary print in modes 1, 2, or 3, the program returns to the EXEC routine which, in turn, calls SUMARY. The overall flow of the program is shown in figure 2.

3.2 Minimum Variance Statistics, Detailed Procedures

3.2.1 Matrix Manipulation by Partitioning

Storage limitations in the B2 (variable states) mode has made it necessary to do most of the matrix multiplication by partitioning of the matrices involved. Illustration of the procedures utilized will be made for the cases:

$P = S\ Q\ S^*$ and

$Q_t = \Lambda\ Q\ \Lambda^*$.

3.2.1.1 Conversion of Q to P

The equation, $P = S\ Q\ S^*$ can be written as:

$$\left[\begin{array}{c|c} P'(6\times 6) & A(6\times n) \\ \hline A^T & B(n\times n) \end{array}\right] = \left[\begin{array}{c|c} S'(6\times 6) & 0 \\ \hline 0 & I \end{array}\right] \left[\begin{array}{c|c} Q'(6\times 6) & C(6\times n) \\ \hline C^* & D(n\times n) \end{array}\right] \left[\begin{array}{c|c} S^*(6\times 6) & 0 \\ \hline 0 & I \end{array}\right]$$

Therefore,

$$|P| = \left[\begin{array}{c|c} S'Q' & S'C' \\ \hline C^* & D \end{array}\right] \left[\begin{array}{c|c} S^{*\prime} & 0 \\ \hline 0 & I \end{array}\right]$$

$$= \left[\begin{array}{c|c} S'Q'(S^*)' & S'C \\ \hline C^*(S^*)' & D \end{array}\right] = \left[\begin{array}{c|c} S'Q'(S^*)' & S'C^* \\ \hline (S'C)^* & D \end{array}\right]$$

Thus, the upper left hand of P is computed by multiplication of 6 x 6 matrices, the lower right hand (n x n) partition requires no multiplication, the upper right hand partition is found from the multiplication of a (6 x 6) by (6 x n) matrices, and the lower left hand partition is the transpose of the upper right hand.

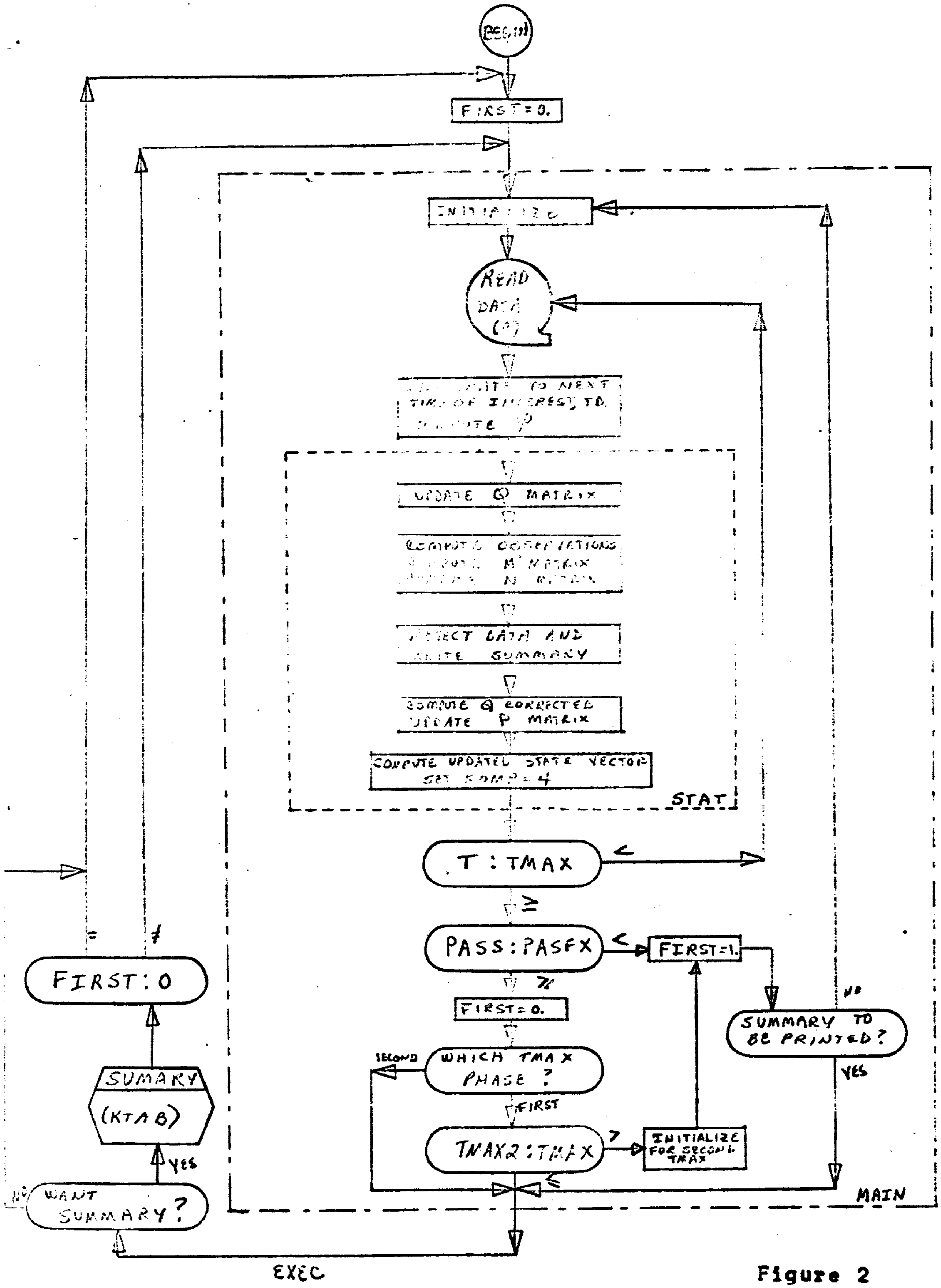

BEGIN
FIRST=0.
READ DATA
UPDATE Q MATRIX
COMPUTE Q CORRECTED
UPDATE P MATRIX
COMPUTE UPDATED STATE VECTOR
STAT
T : TMAX
PASS : PASFX
FIRST=1.
FIRST=0.
SUMMARY TO BE PRINTED?
NO
YES
WHICH TMAX PHASE ?
SECOND
FIRST
TMAX2 : TMAX
INITIALIZE FOR SECOND TMAX
MAIN
FIRST : 0
SUMARY
(KTAB)
YES
NO
WANT SUMMARY?
EXEC

Figure 2

3.2.1.2 Conversion of Q (T_0) to Q (t_d)

The equation, $Q = \Lambda_{(t,t_0)} Q_0 \Lambda^T_{(t,t_0)}$ can be written as

$$\left[\begin{array}{c|c} Q' & A \\ \hline A^T & B \end{array}\right] = \left[\begin{array}{c|c} \Lambda(t,t_0)_{(6\times 6)} & \psi(t,t_0)_{(6\times n)} \\ \hline O & I \end{array}\right] \times \left[\begin{array}{c|c} Q'_{(6\times 6)} & C_{(6\times n)} \\ \hline C^+ & D_{(n\times n)} \end{array}\right] \times \left[\begin{array}{c|c} \Lambda^+_{(t,t_0)} & O \\ \hline \psi^+_{(t,t_0)} & I \end{array}\right]$$

$$= \left[\begin{array}{c|c} (\Lambda Q' + \psi C^+) & \Lambda C + \psi D \\ \hline C^+ & D \end{array}\right] \times \left[\begin{array}{c|c} \Lambda^+ & O \\ \hline \psi^+ & I \end{array}\right]$$

$$= \left[\begin{array}{c|c} (\Lambda Q' + \psi C^+)\Lambda^+ + (\Lambda C + \psi D)\psi^+ & \Lambda C + \psi D \\ \hline (\Lambda C + \psi D)^+ & D \end{array}\right]$$

Thus, the updated Q matrix is made up of an upper left (6 x 6) composed of multiplications of several matrices. The upper right and lower left hand partitions of the matrix, which are transposes, are identical to one portion of the matrix which makes up the upper left (6 x 6). This fact saves recomputing these parts. Finally, the lower right (n x n) of the Q matrix remains unchanged by the translation through the state transition matrix.

3.2.2 Data Rejection

The data rejection process takes place in the STAT routine and consists of comparing the measured residual against the statistical estimate of the residual. If the actual residual falls outside of K sigma times the statistical estimate, it can be rejected if the input flag, IRDATA, is set to 1.

If the data errors were truly randomly distributed, this test would not be necessary. However, it has been found that in many cases, catastrophic errors in the data are indicated. These errors are evidently transient in nature and are not included in estimates of the observation instruments standard deviation.

This part of STAT has been initialized by priming the arrays, B_m (25 x 2) and AREJ (25), which are utilized for printing summary information. The observed data deviations from computed data are stored in particular rows of B_m. For types other than observed data, the deviations have been set to 0. The AREJ region contains BCD information initially equal to blanks.

The M matrix is a rectangular array having dimensions (N_d, n).* It is computed by reference to the partials subroutine. This routine can reduce the value of N_d. In such a case, the particular AREJ would

* N_d is the number of simultaneously measured data parts
n is the number of states being considered

be set to "$". Thus, in SUMARY, the user can readily identify the reason for the rejection of a point. The main processing of the data point is ignored if this reduction produces a zero value for N_d. If N_d is not reduced to zero, the routine performs the following matrix computations.

$$N = M\ S$$

$$Y = N\ Q\ N^* + \bar{e}^2$$

Data rejection occurs if

$$(\Delta)^2_k > FSGM^2 \times (Y_{k,k} + \bar{e}^2_{k,k})$$

where

$Y_{k,k}$ is the variance of the uncertainty in the K^{th} observation due to uncertainties in the state

$\bar{e}^2_{k,k}$ is the covariance of the uncertainty in the K^{th} observation due to uncertainties in the instrumentation.

FSGM in the above equations is an inputted quantity corresponding to the number of σ deviation allowed before a data point is rejected. On the first pass from T_o to TMAX1 or TMAX2, this value is nominally 10. On subsequent passes, it is 3. These values can be altered by the user.

If the observation is rejected, the particular location of AREJ corresponding to the K^{th} observation is equated to the Hollerith "*", and the value of N_d is reduced by unity. The tests for rejection are bypassed if the value of N_d becomes zero.

If N_d is not zero, the following matrix modifications must be performed:

1. The K^{th} row and column of the following matrices must be replaced by the $(K + 1)^{th}$ row and column.

$$[Y] \qquad [\bar{e}^2]$$

2. The K^{th} row of the following matrices must be replaced by the (K + 1) row and column.

$$[Y] \qquad [EBRVAL]$$

The latter matrix is derived from an inputted matrix which served as a multiplier of the $[\bar{e}^2]$ matrix.

The examinations of all observations terminates the data rejection tests. The production of a binary summary tape containing the time, record number, observations, deviations, and the Hollerith indicators which reveal rejection of data is made at this point.

4.0 Program Description, Bayes Statistics

The main flow of statistical filtering by Bayes estimation methods is mechanized in the program by the MAIN and the BAYES subroutines. Because of the similarity in the B1 (minimum states) and B2 (variable states) programs, the use of MAIN and BAYES in the following discussions will imply either the B1 or B2 versions of the two subroutines. Differences in the two versions will be indicated where they exist.

Because of the complexity of this statistical method, a rather detailed description is presented here.

4.1 Bayes Statistics, Timing

Bayes statistics are applied to an interval of a trajectory defined by two values of time. There usually exists one or more observed data points within the interval which are eventually utilized for refinement of the trajectory.

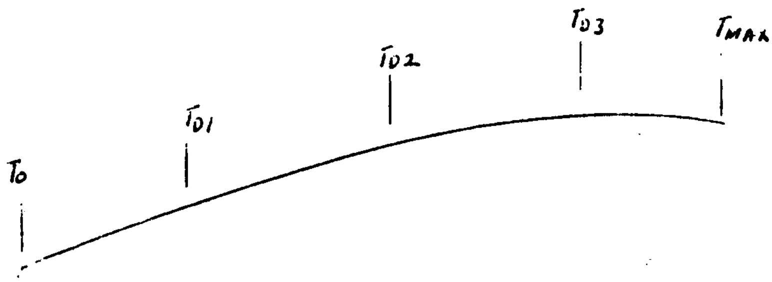


Figure 3

The Bayes routine establishes a time sequence (Figure 3)

$$T_c \quad T_{D_1} \quad T_{D_2} \quad T_{D_3} \quad T_{MAX}$$

at which deviations between the nominal trajectory and the observed data points are accumulated. The accumulated corrections at the end of the interval (also called a "batch") are utilized for statistical correction of the initial conditions of the batch. The initial conditions may differ from the true quantities so that assumed linearity conditions are not met. If this is the case, convergence criteria will not be met and the procedure is restarted with the new initial conditions utilized to generate a new nominal trajectory. The new trajectory is based upon the statistically corrected initial conditions.

Statistically corrected initial conditions are repeatedly improved by application of Bayes estimation until the convergence criteria are met. This condition is known as "convergence". The entire procedure outlined in preceding paragraphs is known as the "pre-convergence" mode.

Each refinement of initial conditions from Bayes modifications is defined as a "pass". The program includes a pass counter, NPASS, which records the number of passes. After every unsuccessful pass, this counter is compared with a pre-assigned maximum permissable value, MXPASS, supplied by the user. An error condition occurs when the counter achieves its maximum value without having achieved convergence.

If convergence is attained, the "post-convergence" mode is entered. The new values for the initial conditions are used to update the trajectory and the covariance matrix to the end of the batch, TMAX. The program contains provisions for continuing in an identical manner with 5 additional batches, their time lengths being described in INPUT as TSPAN(NT) and their parametric and statistical initial conditions being the updated values from the preceding batch.

Figure 4 illustrates the time history of the Bayes program.

Batch #1 extends from $(T_0)_1$ to $(T_{MAX})_1$ - TSPAN (1)

Batch #2 extends from $(T_{MAX})_1$ to $(T_{MAX})_2$ - TSPAN (2)

. . . .

Batch #6 extends from $(T_{MAX})_5$ to $(T_{MAX})_6$ - TSPAN (6) where

$$(T_o)_1 < (T_{MAX})_1 \leq (T_{MAX})_2 < \cdots \leq (T_{MAX})_5 < (T_{MAX})_6$$

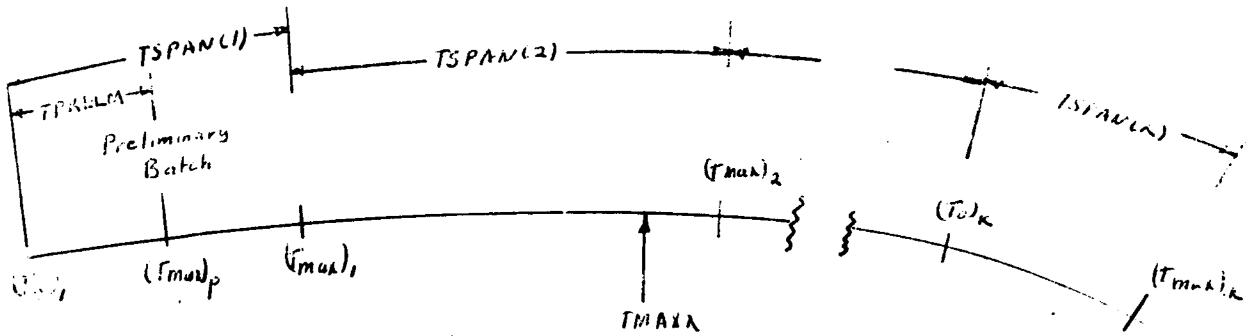


Figure 4

The absolute maximum time for any given run is established by TMAXX. It supersedes all other timing considerations in the program. That TMAXX has been reached in processing any batch of data is indicated by the flag, KLAST, which is used to indicate termination of the program.

One mode of operation of this program allows the processing of a preliminary batch before entering the main logic described above. In Figure 4, the time $(TMAX)_p$, called TPRELM, is the length of this span. TPRELM is an inputted value which must be greater than 0 and less than TSPAN (1) in order for the preliminary batch mode to operate.

The preliminary batch is executed in an effort to achieve initial conditions at $(T_o)_1$ which will reduce the number of passes required for convergence when investigating the longer duration non-preliminary batches.

Tests in MAIN on TPRELM determine the need for the preliminary batch mode and the setting of a flag, MBATCH, to indicate the mode:

MBATCH $\not\leq$ 0 indicates a preliminary batch

MBATCH = 0 indicates a non-preliminary batch.

4.2 Bayes Statistics, General Program Procedures

Figure 5 is a general flow chart showing the interaction of the EXEC, MAIN, BAYES, and SUMARY routines. The principal flags utilized are LSFLAG and JFLAG.

The convergence indicator, LSFLAG, is utilized to indicate the mode of operation. It is set in the BAYES subroutine.

LSFLAG = 0 indicates convergence has not be achieved

LSFLAG $\not\leq$ 0 indicates convergence has been achieved

JFLAG is an indicator which is set within the BAYES subroutine to indicate which task has just been performed.

JFLAG = 0 indicates pre-convergence execution

JFLAG $\not\leq$ 0 indicates execution of the post-convergence mode

The principal steps in the program can be itemized as follows:

1. Set maximum time of the N^{th} batch
2. Read the data tape
3. Integrate to the i^{th} data point
4. Test if in pre-convergence or post-convergence mode; if pre-convergence, write full data set on scratch tape; if post-convergence, write truncated data set on tape.
5. Test present time against TMAX: if less, go to 2 and repeat through 5; if equal or greater, enter BAYES subroutine.

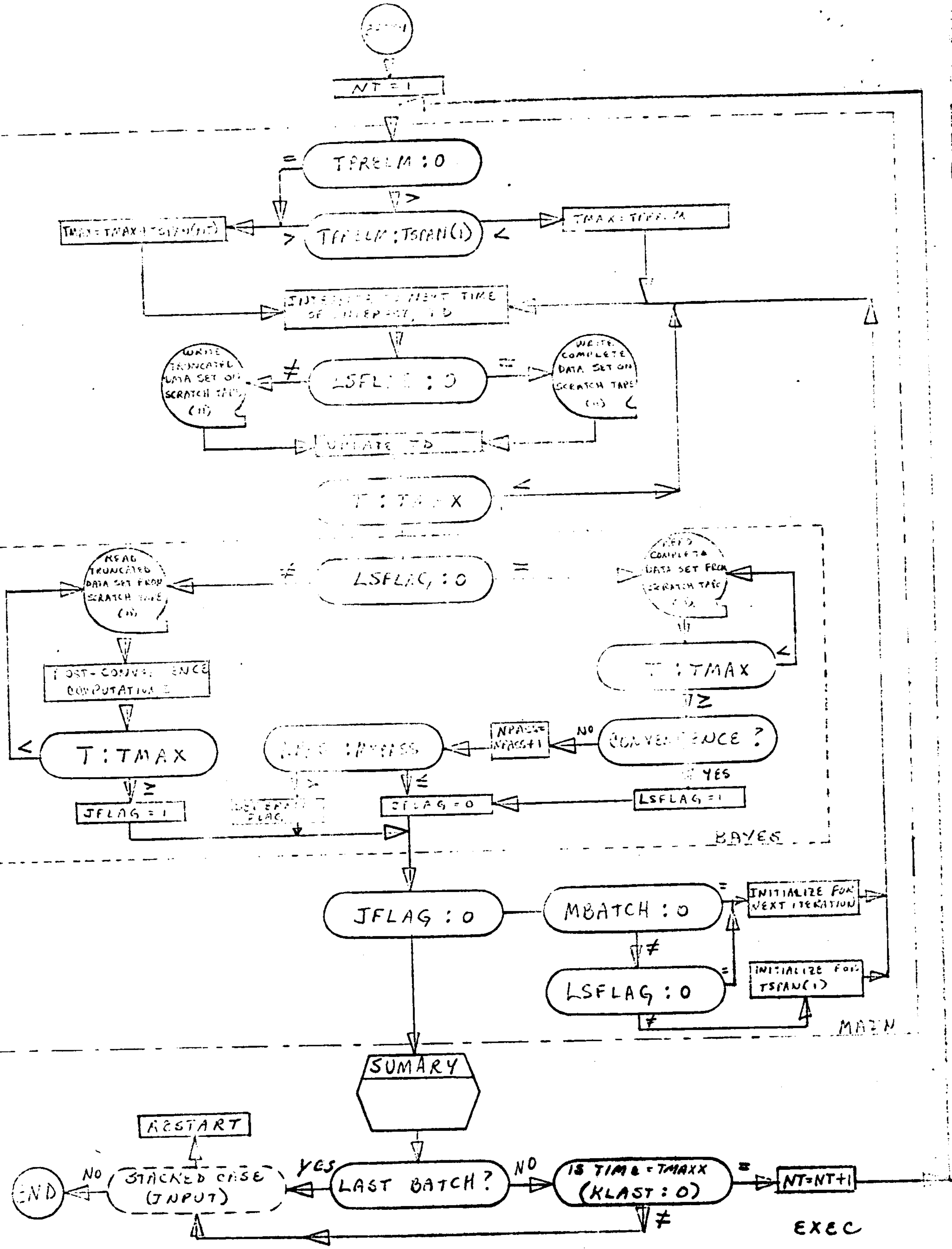

NT = 1
TPRELM : 0
TPRELM : TSPAN(1)
TMAX = TPRELM
INTEGRATE TO NEXT TIME OF INTEREST, TD
WRITE TRUNCATED DATA SET ON SCRATCH TAPE (11)
LSFLAG : 0
WRITE COMPLETE DATA SET ON SCRATCH TAPE
UPDATE TD
T : TMAX
LSFLAG : 0
READ TRUNCATED DATA SET FROM SCRATCH TAPE (11)
READ COMPLETE DATA SET FROM SCRATCH TAPE
POST-CONVERGENCE COMPUTATIONS
T : TMAX
T : TMAX
CONVERGENCE ?
NO
NPASS = NPASS+1
YES
LSFLAG = 1
JFLAG = 1
JFLAG = 0
BAYES
JFLAG : 0
MBATCH : 0
INITIALIZE FOR NEXT ITERATION
LSFLAG : 0
INITIALIZE FOR TSPAN(1)
MAIN
SUMARY
RESTART
END
NO
STACKED CASE (INPUT)
YES
LAST BATCH ?
NO
IS TIME = TMAXX (KLAST : 0)
NT=NT+1
EXEC

Figure 5

6. Test if convergence has occurred. If not, read scratch tape, process and accumulate data, write on summary tape if requested. If so, read scratch tape, update Q matrix and initial conditions and print results.
7. Test present time against TMAX. If less, go to 6 and repeat. If equal to or greater, update initial conditions and go to 8 if in pre-convergence mode - if in post-convergence mode, go to 10.
8. Test for convergence. If convergence has occurred, set LSFLAG to 1 and go to 11. If convergence has not occurred, set LSFLAG to 0 and increment pass counter.
9. Test pass counter. If less than maximum number inputted, set JFLAG to 0 and return to 2 using updated values of the states determined in 7. If greater than maximum number, EXIT.
10. Set JFLAG to 1.
11. Write out summary tape, if requested.
12. Test termination criteria. If yes, EXIT. If no, increment batch counter, N, and return to 1.

4.3 Bayes Statistics, Detailed Procedures

4.3.1 The Satellite Ephemeris Tape

The pre-convergence mode requires that the elements of the nominal trajectory be stored on a (scratch) satellite ephemeris tape. The first logical record on the tape contains a (n x n) double precision matrix which is the inverse of Q_o, the initial covariance matrix.

Observed data and parameters of the nominal trajectory are required at:

1. The beginning of a batch,
2. Each observed data point within the batch,
3. The end of the batch.

A data set is defined as the combination of observed data and computed values. More specifically, a "complete" data set contains the following items:

Record Number

Time, T

Vehicle Position Components, $\bar{R}_c$

Vehicle Velocity Components, $\dot{\bar{R}}_c$

State Transition Matrix, λ_1 --Also λ_2 for the B_2 mode

Un-corrected data time, $T_{K_{RAW}}$

Data Flags, L_T

Observed Data

Additional Data Flags, L_{T_1}

Planet of Interest Indicator, IPLNT

Working Body Reference Indicator, W_{REF}

Position and Velocity Vectors from a Given Planet of Interest to the Reference Body, CPOS and CVEL

These items are defined as follows:

Record Number: Each data point on the data tape is given a number (program symbol, ICOUNT). A record number equal to zero indicates accompanying data which should not be processed. The record numbers of the complete data sets at the beginning and end of a batch will equal zero unless an observed data point is present.

Time: Program symbol is T. It indicates the program time of the complete data set.

$\bar{R}_c$ Position components which have the program symbol RC. It indicates an array of six locations.

$\dot{\bar{R}}_c$ Velocity components which have the program symbol RDC. It indicates an array of six locations.

$[\lambda_1]$ Program symbol is ALAM1 indicating a (6 x 6) matrix. It contains the state transition matrix.

$[\lambda_2]$ Program symbol is ALAM2 indicating a (6 x n) matrix. It contains the state transition matrix for the dynamic biases. n is dimensioned to 20, depending upon the number of dynamic biases considered as states. (Used in B2 mode only.)

T_{KRAW} Un-corrected data time having the program symbol TK RAW.

L_T A series of packed data flags used for interpreting observed data. Symbol is LTEMP.

Data Observed data consisting of four (4) single precision words. The program symbol is DATA.

L_{T1} Additional flags for interpretation of data. Symbol is LTEMP1.

W_{REF} Reference body indicator having program symbol MWREF.

C_{POS} One column of a (6 x 7) array containing the position vector components from a particular body to the reference body. The particular column is determined by the variable IPLNT.

C_{VEL} Sane as C_{POS} except for velocity vector.

IPLNT Indicates a planet number used in on-board observation when a planet is one of the observed bodies.

A "truncated" data set contains all items described in the complete data set with the exception of:

Record Number

TK_{RAW}

L_T

Data

L_{T_1}

C_{POS}

C_{VEL}

The matrices $[\lambda_1]$ and [illegible] are given with respect to lost print time rather than initial time as in full data set.

A typical tape configuration for the pre-convergence mode is shown in Figure 6. It applies to a batch having three data points where no data occurs at the beginning or end of the batch.

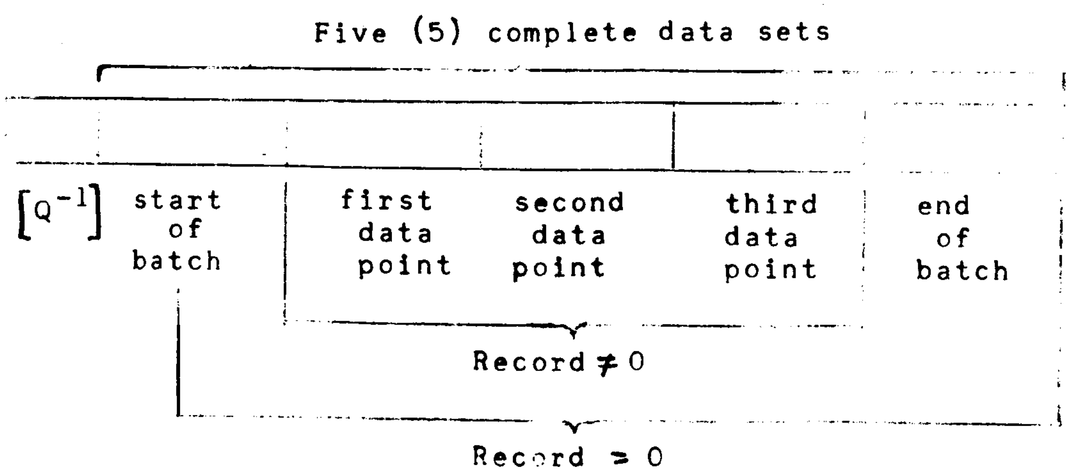


Figure 6

A typical tape configuration for the post-convergence mode is shown in Figure 7.

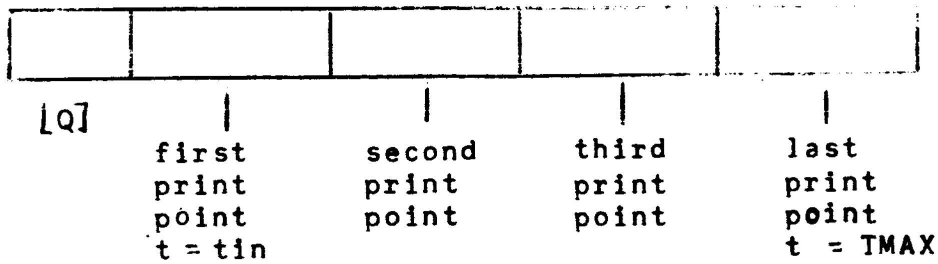


Figure 7

At the initial entry into the program, the Q^{-1} matrix is written on the tape by INPUT. At the start of processing on subsequent batches, this matrix is written by BAYES subroutine. The Q matrix on the post-convergence mode tape is written by BAYES. All other information is written by the MAIN program. Reading of the tape is done completely by the BAYES routine.

4.3.2 Initialization Procedures

Initialization procedures include the preservation of position and velocity components at the beginning of the batch.

$$\bar{R}'_c = \bar{R}_c$$

$$\dot{\bar{R}}'_c = \dot{\bar{R}}_c$$

The "D" matrix isan (n x 1) array which serves in an accumulator capacity in the subsequent computation. Initially,

$$[D] = [Q^{-1}]\Delta\alpha$$

A tally of the usable observed data points is required at the end of the batch. This counter must be equated to zero before main processing.

$$N_{DATA} = 0$$

4.3.3 Pre-Convergence Mode - Loading Data

The record number of the first complete data set will equal zero. This circumstance must be followed by a reading of the next complete data set. A non-zero record number indicates served data which must be processed before reading another set.

A data set following the first set may be ignored by equating its record number to zero. A second test of record number guarantees processing of a subsequent data set only if the record number is not zero.

The station number and data type list are obtained from the packed word, L_T. The sub-program "FIX" is referenced for this purpose. The data type list contains four entries corresponding to the observations at a particular station. Each entry of the list is extracted from the sequence of integers (1 to 25) which corresponds to the total number of different types of observations. The number of observations, N_D, is defined as the number of non-zero entries in the data type list. The value of N_D may not exceed four (4).

Under certain conditions indicated by the flag word, L_{T1}, and the station number, it is necessary to modify the "UP" frequency of the tracking signal (F_1). This item is implicitly required by sub-routines referenced in later sections of the program.

The Y_{OBS} array contains twenty-five double precision locations. At a data point, the program utilizes only N_D of these locations. The particular locations are determined by the data type list. The actual information stored in these particular locations is obtained from the four single precision data words which were loaded via the nominal tape. The user must observe the requirement of four data words in a complete data set regardless of the value of N_D. Zero entries in the data type list correspond to entries of 10^{10} in the four data words;

i.e., if $N_D = 0$ Words 1, 2, 3, 4 are 10^{10}

if $N_D = 1$ Word 1 is data
Words 2, 3, 4 are 10^{10}

if $N_D = 2$ Words 1, 2 are data
Words 3, 4 are 10^{10}

if $N_D = 3$ Words 1, 2, 3 are data
Word 4 is 10^{10}

if $N_D = 4$ Words 1, 2, 3, 4 are data

The data words in a complete data set refer to actual observed data. The position and velocity vectors of the same refer to computed values of a theoretical trajectory generated by numerical integration. Position and velocity must be transformed into the same measuring systems utilized by the actual observed data. The Y_{COM} array contains twenty-five locations of which N_D particular locations are utilized. The particular locations are determined by the observations sub-program, which also computes deviations between observed and computed data. The deviations are stored in a $(N_D \times 1)$ array, $[\Delta Y]$.

4.3.4 Pre-Convergence Mode - Data Rejection

The data rejection section is very similar to the procedures utilized in Kalman Filter statistical processing. This part of the routine is initialized by priming the arrays, B_M (25 x 2) and A_{REJ} (25), which are utilized for printing summary information. The observed data and deviations from computed data are stored in particular rows of B_M. For types other than observed data, other deviations have been set to 0. The A_{REJ} region contains BCD information initially equal to blanks.

The "M" matrix is a rectangular array having dimensions (N_D, n). It is computed by reference to the partials sub-routine. This routine could reduce the value of N_D. In such a case, the particular AREJ would be set to "$". The main processing of the data point is ignored if this reduction produces a zero value for N_D. If N_D is not reduced to zero, the routine performs the following matrix computations:

$$|N| = |M| \cdot |S|$$

$$|B| = |N| \cdot |\lambda|$$

$$|Y| = |B| \cdot |Q_o| \cdot |B|^*$$

The matrix "Q_o" in the preceding computation is a (6 x 6) double precision array transmitted from the calling routine to least squares via core storage. It corresponds to the "Q" matrix transmitted to the routine via the nominal tape. It is necessary to allot two areas of storage for this matrix due to the eventual modification of the "Q" matrix when data points are encountered. In short, the data rejection section utilizes a constant "Q" matrix, Q_o, which is not subjected to modification. In the B2 mode, this Q_o matrix is the upper left hand 6 x 6 portion of the total n x n inputted covariance matrix.

The "Y" matrix in the preceding equations is an ($N_D \times N_D$) array which should be symmetrical. The loss of similarity due to round-off is reduced by referencing the subroutine, "SYMMAT", which averages opposing elements.

Let (k), represent the particular observation under examination.

$$k = 1, \ldots, N_D$$

Data rejection occurs if

$$(\Delta Y)_k^2 = F_{SGM}^2 \times (Y_{k,k} + \bar{e}_{k,k}^2)$$

where

$[Y_{k,k}]$ is the variance of the uncertainty in the K^{th} observation due to the uncertainty in the state

$[\bar{e}_{k,k}^2]$ is the variance of the uncertainty in the K^{th} observation due to the uncertainties in the instrumentation.

FSGM is an inputted quantity quantity corresponding to the allowable deviation in σ's allowed before a data point is rejected because it falls outside of reasonable statistical limits. FSGM = 10 is a typical value.

If the observation is rejected, the particular location of A_{REJ} corresponding to the k-th observation is equated to the Hollerith "*", and the value of N_D is reduced by unity. The tests for rejection are by-passed if the value of N_D becomes zero.

If N_D is not zero, the following matrix modifications must be performed:

1. The k-th row and column of the following matrices must be replaced by the (k + 1) row and column.

   $\left| Y \right| \qquad \left| \bar{e}^2 \right|$

2. The k-th row of the following matrices must be replaced by the (k + 1) row.

   $\left\lfloor Y \right. \qquad \left| B \right|$

The examinations of all observations terminates the data rejection tests. The production of a binary summary tape containing the time, record number, observations, deviations, and the Hollerith indicators which reveal rejection of data is made at this point.

4.3.5 Pre-Convergence Mode - Data Accumulation

After processing each data point, the inverse of the "Q" matrix is up-dated by adding:

$$\left| B \right|^{*} \cdot \left| \bar{e}^2 \right|^{-1} \cdot \left| B \right| \quad \text{and}$$

the "D" matrix is up-dated by adding:

$$\left| B \right|^{*} \cdot \left| \bar{e}^2 \right|^{-1} \cdot \left| \Delta Y \right|$$

Before testing for an "end-of-batch" condition, it is necessary to up-date the tally of the usable observed data points, N_{DATA}.

4.3.6 Pre-Convergence Mode - End of Batch

The "end-of-batch" condition is indicated by observing an equality between time, T, and the time indicating "end-of-batch", T_{MAX}. If "end-of-batch" is not indicated, the routine repeats the preceding logic by reading the next complete data set from the nominal tape.

A reading of zero in the tally of the usable observed data points indicates a total rejection of every point within the batch. The entire batch is disregarded when this circumstance occurs. The convergence indicator is set to the position which indicates convergence (LS FLAG = 1).

If N_{DATA} is not zero, the end-of-batch equations are

$$\left[Q' \right] = \left[Q^{-1} \right]^{-1}$$

and

$$\left[\Delta \alpha \right] = \left[Q' \right] \cdot \left[D \right]$$

The six values of $\left[\Delta \alpha \right]$ are utilized for statistically modifying the initial position and velocity components

x $(= R_{c1})$ is modified by $\Delta \alpha_1$

y $(= R_{c2})$ is modified by $\Delta \alpha_2$

z $(= R_{c3})$ is modified by $\Delta \alpha_3$

$\dot{x}$ $(= R_{c1})$ is modified by $\Delta \alpha_4$

$\dot{y}$ $(= R_{c2})$ is modified by $\Delta \alpha_5$

$\dot{z}$ $(= R_{c3})$ is modified by $\Delta \alpha_6$

A reference to the subroutine, DALFA, accomplishes these modifications as well as computing $\Delta \chi$, the deviation of the initial conditions from those originally found.

The pass counter, NPASS, is tested if convergence fails. The pass counter is incremented after convergence fails until it achieves its maximum permissable value, MXPASS. Failure to achieve convergence within the maximum number of passes through the BAYES routine indicates an error condition.

If the pass counter has not achieved its maximum value, the routine re-positions the nominal tape to the end of the inverse of the "Q" matrix. The next execution of the nominal trajectory can write new complete data sets on tape without any subsequent re-positioning.

The convergence indicator is set to indicate convergence if both tests are successful. If the routine is operating on a preliminary batch, it must reposition the tape by reading a single logical record. The inverse of "Q" is not replaced when processing a preliminary batch. A bath other than a preliminary batch requires overwriting the first record on tape by the "Q" matrix updated to TMAX.

4.3.7 Post Convergence Mode

The MAIN program computes a refined trajectory after convergence has been achieved (LS FLAG = 1). During the computation of the refined trajectory, the MAIN program generates a nominal tape containing the "Q" matrix (n x n) as the first logical record. This "Q" matrix is written on tape by the final section of the pre-convergence mode.

The computation of the refined trajectory requires the MAIN program to write a truncated data set at pre-selected print times and at the terminal points of the batch.

The BAYES routine in the post-convergence mode reads the "Q" matrix and one truncated data set. An error condition occurs if the time, (T), of the first data set does not agree with the time of the beginning of the batch, (T_0).

The post-convergence mode up-dates the "Q" matrix at each point within the batch. No processing is required at the beginning of the batch. At the (i)-th data point

$$[Q]_i = [\lambda]_i [Q]_{i-1} [\lambda]_i^*$$

The P matrix is computed from the equation

$$[P]_i = [S]_i \cdot [Q]_i \cdot [S]_i^*$$

It is printed, if requested.

At $T = T_{MAX}$ the "Q" matrix has been propagated to the end of the batch. The first (6 x 6) elements must be preserved in core storage for the data rejection computation of the next batch.

$$[Q_0]_{6x6} = [Q]_{6x6}^{**}$$

** upper left 6 x 6 in the B2 mode.

The propagated "Q" matrix inverse is written on the nominal tape as the first logical record. The program is now ready to repeat the above flow for the second and subsequent batches of data.

5.0 Common Definitions

5.1 Exec. A and Exec. B1 Blank Common

5.1.1 Double Precision

Variable Name	Description
AUERAD	CONVERSION FACTOR-AU TO ER
BETA	DIFFERENTIAL ECCENTRIC ANOMALY
CDS(3)	REFERENCE FREQUENCIES USED IN DSIF SYSTEM
CKMER	CONVERSION FACTOR-ER TO KM =1.56784906D-4
CKSERH	CONVERSION FACTOR-ER/HR TO KM/SEC =.05644256616D0
COMB(1)	VELOCITY OF LIGHT
CONST(25)	CONVERSION FACTORS FOR PRINTING OUT OBSERVATIONS
CPO[illegible])	BLOCK OF REFERENCE BODY POSITIONS
CPRI(3)	CONSTANTS USED IN DSIF SYSTEM
CRAD	CONVERSION FACTOR- DEG TO RAD =.01745329251994 3D0
CT	NUMBER OF JULIAN CENTURIES FROM 0-HRS 1/1/50 TO PRESENT
CVEL(6,7)	BLOCK OF REFERENCE BODY VELOCITIES
CZ	VALUE OF C AT RECTIFICATION POINT
D	NUMBER OF DAYS FROM 0-HRS 1/1/50 TO PRESENT
DELTP	CURRENT PRINT INTERVAL WHEN NOT PROCESSING DATA
DIN	NUMBER OF DAYS FROM 0-HRS 1/1/50 TO 0-HRS OF LAUNCH YEAR
DPADD(25)	ARRAY OF DOUBLE PRECISION VARIABLES
DSPL	SPECIAL INTEGRATION INTERVAL IN A4 MODE TO GET ACQUISITION TIME
DT	NUMBER OF JULIAN CENTURIES FROM PRESENT TO BASE DATE
DT3(3,7)	RUNGE-KUTTA INTEGRATION INTERVALS FOR NEAR, MEDIUM AND FAR REFERENCE
DTI	CURRENT INTEGRATION INTERVAL
DYN(60)	ARRAY OF DYNAMIC STATES
DZ	VALUE OF D AT RECTIFICATION POINT
E	NUTATION IN OBLIQUITY
EF1	SUBSIDIARY OUTPUT FROM KEPLER
EF2	SUBSIDIARY OUTPUT FROM KEPLER
EF6	SUBSIDIARY OUTPUT FROM KEPLER
EF7	SUBSIDIARY OUTPUT FROM KEPLER
EMIN	MINIMUM ELEVATION ANGLE (RADIANS)
EO	NOT PRESENTLY USED
EPSSQ	SQUARE OF EARTH'S ELLIPTICITY =6.693422D-3
EQ	MEAN OBLIQUITY
ERAD	EARTH'S RADIUS IN KM = 6378.165D0
GAM(3,3)	TRANSFORMATION MATRIX FROM ROTATING GEOCENTRIC SYSTEM TO INERTIAL SYSTEM
GAMM	GREENWICH HOUR ANGLE
GHA(3,3)	ORTHOGONAL TRANSFORMATION MATRIX
HMU	GRAVITATIONAL CONSTANT OF REFERENCE BODY
OBSPLS(9)	UNIT VECTORS DESCRIBING STATION-VEHICLE RELATIONSHIP
OLDT	PREVIOUS DTI
OLEL	SAVED ELEVATION ANGLE

ORM	MAGNITUDE OF THE POSITION VECTOR RCMSC
OVB(3)	VELOCITY VECTOR BETWEEN STATION AND VEHICLE
PEROBL(3)	OBLATENESS PERTURBATION
PFPAR(3,9)	VALUES OF SPECIFIED SETS OF POWERED FLIGHT PARAMETERS
PI	180 DEGREES IN RADIANS =3.141592653589793D0
PRENUT(3,3)	PRECESSION-NUTATION MATRIX
PRNT3(3)	PRINT INTERVALS FOR NEAR, MEDIUM AND FAR REFERENCE
PROPNL(3,3)	PRECESSION-NUTATION-LIBRATION MATRIX
PSI	NUTATION IN LONGITUDE
R1(7)	DISTANCES IN ER FOR EACH OF 7 BODIES FOR SWITCHING FROM NEAR TO MEDIUM INTEGRATION INTERVALS
R2(7)	DISTANCES IN ER FOR EACH OF 7 BODIES FOR SWITCHING FROM MEDIUM TO FAR INTEGRATION INTERVALS
RA	RECIPROCAL OF SEMI-MAJOR AXIS OF ORBIT
RATEV(3,2)	ROTATION VECTORS USED IN MARS AND VENUS DRAG COMPUTATIONS
RC(6)	INSTANTANEOUS POSITION VECTOR
RCIN(3)	INITIAL POSITION VECTOR
RCINT(6)	SAVED VALUE OF RC
RCMSC(3)	POSITION VECTOR BETWEEN STATION AND VEHICLE
RDC(6)	INSTANTANEOUS VELOCITY VECTOR
RDCIN(3)	INITIAL VELOCITY VECTOR
RDCINT(6)	SAVED VALUE OF RDC
RDDOT(3)	PERTURBATIONS OF COWELL INTEGRATION
RDDOTS(3)	SAVED VALUE OF RDDOT
RDI(6)	VELOCITY VECTOR AT LAST RECTIFICATION
RDTB(6)	TWO-BODY VELOCITY VECTOR
RI(6)	POSITION VECTOR AT LAST RECTIFICATION
RRATE(4,26)	REPETITION RATES OF STATIONS OBSERVATIONS
RT1	VALUE USED AS TOLERANCE IN RECTIFICATION CRITERIA
RT2	VALUE USED AS TOLERANCE IN RECTIFICATION CRITERIA
RTB(6)	TWO-BODY POSITION VECTOR
SAVD	SAVED VALUE OF DTI
SCALE(3)	ARRAY OF SCALE FACTORS FOR PRINTING TRAJECTORY INFORMATION
SEC	SECONDS OF LAUNCH MINUTE
SQTMU	SQUARE ROOT OF HMU
STAC(3)	CURRENT STATION COORDINATES
STAHT(26)	ARRAY OF STATION ALTITUDES
STALN(26)	ARRAY OF STATION LONGITUDES
STALT(26)	ARRAY OF STATION LATITUDES
STAOR(442)	ARRAY OF STATION-ORIENTED STATES
SVL	SAVED VALUE OF L DIRECTION COSINE
SVM	SAVED VALUE OF M DIRECTION COSINE
T	CURRENT TIME (HRS)
TAQ	ACQUISITION TIME
TB	NUMBER OF JULIAN CENTURIES FROM O-HRS 1/1/50 TO BASE DATE
TBF	F COEFFICIENT IN TWO BODY COMPUTATION
TBFD	F DOT COEFFICIENT IN TWO BODY COMPUTATION
TBG	G COEFFICIENT IN TWO BODY COMPUTATION
TBGD	G DOT COEFFICIENT IN TWO BODY COMPUTATION
TD	NEXT ACTIVITY TIME
TH	DIFFERENTIAL ECCENTRIC ANOMALY (ESTIMATE)

TI	TIME OF LAST RECTIFICATION
TINT	SAVED VALUE OF T
TKEP	TIME OF KEPLER REFERENCE
TL	INTERMEDIATE TIME OF EXIT FROM COWELL INTEGRATOR
TMAX	CURRENT MAXIMUM TIME
TPMAT(3,3)	TEMPORARY MATRIX
TPMAT1(3,3)	TEMPORARY MATRIX
TPMAT2(3,3)	TEMPORARY MATRIX
TPMAT4(6)	TEMPORARY MATRIX
TPMAT5(6)	TEMPORARY MATRIX
TPMAT6(6)	TEMPORARY MATRIX
TPMAT7(6)	TEMPORARY MATRIX
TPMAT8(25)	TEMPORARY MATRIX
TPMAT9(21)	TEMPORARY MATRIX
TPMT10(6,6)	TEMPORARY MATRIX
TPMT11(6,6)	TEMPORARY MATRIX
[illegible](4,26)	ARRAY OF NEXT OBSERVATION TIMES FOR EACH STATION
TSSA	SAVED VALUE OF T
TSUBN	EARLIEST OBSERVATION TIME
TSVT(6)	ARRAY OF SAVED TIMES FOR TEST PURPOSES
TTMAT1(3,3)	NUTATION MATRIX
TTMAT3(3,3)	PRECESSION MATRIX
TWOPI	360 DEGREES IN RADIANS =6.283185307179586D0
TZEPH	NUMBER OF HRS FROM BEGINNING OF LAUNCH YEAR TO LAUNCH TIME
TZHRS	NUMBER OF HOURS FROM 0-HRS 1/1/60 TO LAUNCH TIME
WE	EARTH ROTATION RATE
XC	MEAN LONGITUDE OF DESCENDING NODE OF MOON'S MEAN EQUATOR
XFAC	ARGUMENT OF SERIES EXPANSION IN TWO-BODY SOLUTION
XM(3,3)	LIBRATION MATRIX
XO	MEAN LONGITUDE OF THE MOON
YCOM(25)	ARRAY OF COMPUTED VALUES OF OBSERVATIONS

5.1.2 Single Precision

Variable Name	DEFINITION
AMUD	INDICATOR WHOSE VALUE REPRESENTS A CERTAIN ERROR CONDITION
CDT(40)	TABLE OF DRAG COEFFICIENTS
CEPID	INDICATOR FOR COWELL OR ENCKE INTEGRATION
CNT	INTEGRATION FLAG
CWLIN(9)	PERTURBATION VALUES AND THEIR 1ST AND 2nD DERIVATIVES
CWLINT(9)	SAVED VALUES OF CWLIN ARRAY
DAREA	EFFECTIVE SURFACE AREA OF VEHICLE PERTAINING TO DRAG
DAREAS	SAVED VALUE OF DAREA
DAYS	DAYS OF LAUNCH YEAR
DELTA	ELEVATION ANGLE ERROR IN REFRACTION
DH1	REFRACTION INCREMENT IN TROPOSPHERE (KM)

DH2	REFRACTION INCREMENT IN IONOSPHERE (KM)
DTPI	PRINT PORTION (HRS) OF TOTAL PRINT PERIOD
F1	UP FREQUENCY OF TRACKING SIGNAL
F2	DOWN FREQUENCY OF TRACKING SIGNAL
FDOWN(26)	ARRAY OF STATION RECEIVER FREQUENCIES
FKPR	FLOATING POINT PRINT INDICATOR
FPK	INDICATOR FOR TIME DIRECTION $\neq 1$ - FORWARD IN TIME $= -1$ - BACKWARD IN TIME
FUP(26)	ARRAY OF STATION TRANSMITTER FREQUENCIES
H2	LOWER LIMIT OF IONOSPHERE (KM)
H4	UPPER LIMIT OF IONOSPHERE (KM)
HACC	ACCUMULATED ALTITUDE OF ITERATION IN REFRACTION
HMIN	MINUTES OF LAUNCH HOUR
HRS	HOURS OF LAUNCH DAY
I365	INTEGER =365
IBP	INDICATOR FOR INITIALIZATION OF BURN PERIOD
IBSTAT	NOT PRESENTLY USED
ICOUNT	COUNT NUMBER OF DATA POINT
ID	TIME DIRECTION INDICATOR =0 - TMAX > 0 =1 - TMAX < 0
IDER	INTEGRATION INDICATOR
INPERR	INPUT ERROR INDICATOR
IOBLAT(26)	INDICATORS OF DESIRED OBLATENESS COEFFICIENTS (10N/M)
IP	INDICATOR OF NUMBER OF RUNGE-KUTTA STEPS
IPFT	NUMBER OF THE POWERED FLIGHT SET BEING USED
IPLNT	NUMBER OF PLANET TO BE USED FOR COMPUTING ONBOARD OBSERVATIONS
IPINT	SAVED VALUE OF IP
IPS	TIME DIRECTION INDICATOR =0 - TOWARD TMAX =1 - TOWARD 0
IPSEC(10)	INDICATORS FOR PRINTING TRAJECTORY INFORMATION
IRT	INDICATOR FOR BYPASSING INTEGRATION
ISTAR	NUMBER OF STAR TO BE USED FOR COMPUTING ONBOARD OBSERVATIONS
IXADD(25)	INTEGER ARRAY
KECLPS	INDICATOR FOR PRINTING ECLIPSE INFORMATION
KLIBR	INDICATOR FOR LIBRATION OF VECTORS
KM(4)	A MODE-INDICATOR FOR WHICH OBSERVABLES ARE TO BE PROCESSED B1 MODE-UNPACKED STATYP ARRAY FOR CURRENT STATION
KOBLAT	NUMBER OF OBLATENESS COEFFICIENTS
KOMP	INDICATOR FOR CRITERION LEADING TO RECTIFICATION
KRF	INDICATOR FOR REFRACTION COMPUTATIONS
KS2BY	INDICATOR FOR TWO-BODY INTEGRATION ONLY
KSDRG	INDICATOR FOR EARTH DRAG PERTURBATION
KSDRGM	INDICATOR FOR MARS DRAG PERTURBATION
KSDRGV	INDICATOR FOR VENUS DRAG PERTURBATION
KSMNOB	INDICATOR FOR MOON OBLATENESS PERTURBATION

KSNAP	INDICATOR FOR PRECESSION-NUTATION
KSOBL	INDICATOR FOR OBLATENESS PERTURBATIONS
KSPLT	INDICATOR FOR PLANETARY PERTURBATIONS
KSRAP	INDICATOR FOR RADIATION PRESSURE PERTURBATION
KSTA	CURRENT STATION NUMBER
KSTDRD	INPUT INDICATOR FOR STANDARD VALUES
KWBMU(7)	ARRAY OF WORKING BODIES
LEVEL	NOT PRESENTLY USED
LFL	MODE INDICATOR
LML	MODE INDICATOR FOR INTEGRATION
M6	INTEGER= 6
MAXLUN	MAXIMUM NUMBER OF LUNAR LANDMARKS
MAXSTA	TOTAL NUMBER OF STATIONS CONSIDERED
MBMAX	TOTAL NUMBER OF WORKING BODIES CONSIDERED
MDE	MODE
MFLAG	INDICATOR FOR COMPLETION OF A PASS
MINUS1	INTEGER =-1
MINUS2	INTEGER =-2
MPLUS1	INTEGER = 1
MPLUS2	INTEGER = 2
MPLUS3	INTEGER = 3
MPLUS4	INTEGER = 4
MRREF	SAVED VALUE OF INITIAL REFERENCE BODY
MWREF	CURRENT REFERENCE BODY
NA(4,26)	A MODE-ARRAY OF COUNTS FOR TIMING IN A2,A3,A4 MODES B1 MODE-CTR USED IN DETERMINING ACCEPTANCE TIMES FOR DATA TYPES
NCDST	INDEX FOR STATION BEING PROCESSED
NEL	INDICATOR FOR A4 MODE
NPFSET	NUMBER OF POWERED FLIGHT SETS
NUMDAT	CURRENT NUMBER OF OBSERVABLES AT STATION
NUMT	COUNTER USED IN PRINTA AND PB1A
NUT	A MODE- COUNTER FOR A1 MODE B1 MODE- CONTROL FOR INITIAL TIME OF PASS
NYEARP	YEAR OF LAUNCH
OLDYR	NOT PRESENTLY USED
ONE	FLOATING POINT=1.0
PAREA	EFFECTIVE SURFACE AREA OF VEHICLE PERTAINING TO RADIATION PRESSURE
PAREAS	SAVED VALUE OF PAREA
PASF	TOTAL NUMBER OF PASSES FOR FIRST TIME ARC
PASFX	SAVED VALUE OF PASF
PASS	CURRENT PASS NUMBER
PC(3)	NOT PRESENTLY USED
PFON	INDICATOR FOR POWERED FLIGHT
POSLUN(2,10)	LUNAR POSITION TABLE NEEDED BY SUBROUTINE ONBRD
PRATE	PRINT INTERVAL WITHIN DTPI INTERVAL
PRECIS	INDICATOR FOR PRECISION LEVEL
PURP	INTEGRATION INDICATOR FOR WHETHER A OR B1 MODE
PVALPH(3)	BCD ARRAY FOR PRINTING OUT PROPER UNITS
RADII(7)	RADIUS OF EACH OF 7 WORKING BODIES (ER)
RTO	RATIO OF NORDSIECK INTEGRATION INTERVAL TO THAT IN RUNGE-KUTTA

SIXTY	FLOATING POINT =60.0
SPADD(25)	SINGLE PRECISION ARRAY
STANM(26)	ARRAY OF STATION NAMES
STAR(2,10)	STAR TABLE NEEDED BY SUBROUTINE ONBRD
SUMCOM(3)	ARRAY OF CONSTANTS
TAU	PRINT INDICATOR
TDELAY(4,26)	TIME (HRS) BEFORE WHICH OBSERVATION IS NOT TO BE COMPUTED
THREE	FLOATING POINT =3.0
TSTRO	INDICATOR FOR SAVING INTEGRATION VALUES
TWO	FLOATING POINT = 2.0
TWT4	FLOATING POINT =24.0
TYPE(26)-INTEGER	ARRAY OF OBSERVATION TYPES DESIRED - PACKED
TZERO	LAUNCH TIME IN HOURS
USETYP(4)-INTEGER	UNPACKED TYPE ARRAY FOR CURRENT STATION
VMASS	MASS OF VEHICLE
XLST	LOCAL SOLAR TIME USED IN DRAG COMPUTATION
XKN	TOTAL NUMBER OF HOURS IN THE LAUNCH YEAR
XMACH(40)	TABLE OF MACH NUMBERS
XNNEW	CURRENT INDEX OF REFRACTION
YEAR	FLOATING POINT NYEARP

5.2 EXECA AND EXECB1 LABELLED COMMON

/CPF/		POWERED FLIGHT SUBROUTINES PFLGHT, PFINIT
U(62,6)	-D.P.-	ARRAY OF CHEBYSHEV COEFFICIENTS
TMAXPF	-D.P.-	RELATIVE TIME AT END OF BURN PERIOD
TSTART	-D.P.-	STARTING TIME OF BURN PERIOD
LIMIT2	-S.P.-	NUMBER OF CHEBYSHEV COEFFICIENTS
/EPHMM/	INPUTA, EXECA, EPHEM, INPTB1, EXECB1	
TABLE (210)	-S.P.-	PLANTETARY POSITIONS FROM EPHEMERIS TAPE

5.3 EXECB1 Labelled Common

/C1B1/ All EXEC B1 Subroutines Except Trajectory

5.3.1 Double Precision

Variable Name	Description
ALAM1(6,6)	STATE TRANSITION MATRIX
ALMAT(6,6)	TEMPORARY MATRIX
DELALP (6)	VARIATION IN ALPHA PARAMETERS
DELX(6)	VARIATION IN STATE VARIABLES
DELY(4)	ERROR IN OBSERVATIONS
DTK	TIME INCREMENT USED FOR TIME CORRECTION
DTL	INCREMENT USED TO COMPUTE TL
DTP	INCREMENT USED TO COMPUTE TP
EBAR(4,4)	COVARIANCE MATRIX OF OBSERVATIONS
FRQ	REFERENCE FREQUENCY IN DSIF SYSTEM
OVSB(3)	VELOCITY VECTOR OF STATION
PREVTN	PREVIOUS VALUE OF TD
QSAVE(6,6)	INITIAL Q MATRIX
SAVEL1(6,6)	TEMPORARY MATRIX
SMAT(6,6)	S OR S-INVERSE MATRIX - ALSO TEMPORARY MATRIX
STAT(6,6)	CURRENT Q MATRIX
TIN	INITIAL TIME OF PASS
TK	DATA POINT TIME MODIFIED BY TIME CORRECTION
TKRAW	DATA POINT TIME OFF DATA TAPE
TMAXX	UPPER TIME LIMIT FOR RUN
TMAX2	MAXIMUM TIME OF SECOND TIME ARC
TOLSQ	SQUARE OF TOLERANCE OF CONVERGENCE IN LEAST SQUARES
TP	PRINT TIME
TPRELM	MAXIMUM TIME OF PRELIMINARY BATCH IN LEAST SQUARES
TSPAN(6)	ARRAY OF TIME SPANS FOR EACH BATCH IN LEAST SQUARES
TSUBM	NEXT PRINT TIME
TX	TEMPORARY STORAGE OF INITIAL TIME
TY	TEMPORARY STORAGE OF FINAL TIME
XNCY	NUMBER OF CYCLES
YOBS(25)	OBSERVED VALUES OF OBSERVATIONS
YOBSNU	CONSTANT = 1.D10 FOR OBSERVATION TESTS
YRTEMP(6)	TEMPORARY STORAGE IN OBSERVATION COMPUTATIONS
YTEMP(2)	TEMPORARY STORAGE IN OBSERVATION COMPUTATIONS

5.3.2 Single Precision

Variable Name	Description
AREJ(25)	OBSERVATION REJECTION INDICATORS FOR SUMMARY TAPE
BMAT(25,2)	SINGLE PRECISION OBSERVATIONS FOR SUMMARY TAPE
CLUE	INDICATOR IN TIME CORRECTION
C1TAB(3)	CONSTANTS ASSOCIATED WITH RANGE-RANGE RATE SYSTEM

C2TAB(4,2)	ARRAY OF CYCLE COUNTS ASSOCIATED WITH RANGE-RANGE RATE SYSTEM
C3TAB(4)	ARRAY OF UP FREQUENCIES ASSOCIATED WITH RANGE-RANGE RATE SYSTEM
DATA(4)	TEMPORARY STORAGE OF OBSERVATION DATA
DATTYP(4)-INTEGER	THE OBSERVATION TYPES FROM THE DATA TAPE
EBRMLT(4,26)	MODIFIERS FOR DATA COVARIANCE MATRIX FOR STATIONS
EBRVAL(4)	EBRMLT FOR THE CURRENT STATION
FIRST	INDICATOR FOR FIRST TIME THROUGH MAIN
FPIP	FLOATING PT IPS
IPMAT	INPUT INDICATOR FOR READING P OR Q MATRIX
IGUESS	CURRENT VALUE OF RANDOM NUMBER
IMODE	MODE
IMODES	SAVED VALUE OF IMODE
IPSS	SAVED VALUE OF IPS
IQZERO	INDICATOR FOR GROWN OR INPUT Q MATRIX
IRDATA	INDICATOR FOR DATA REJECTION
ISTAT	INDICATOR FOR MINIMUM VARIANCE OR LEAST SQUARES
ISUMRY	INDICATOR FOR SUMMARY TAPE
ITERS	INDICATOR FOR READING IN DATA TAPE
ITER2	ITERATION INDICATOR
JFLAG	EXIT INDICATOR FROM LEAST SQUARES
JRNG	NOT PRESENTLY USED
KFLAG	INDICATOR FOR BATCH TYPE IN LEAST SQUARES
KLAST	INDICATOR FOR FINAL LEAST SQUARES BATCH
KOMPS	SAVED VALUE OF KOMP
KOPT	PRINT OPTION INDICATOR FOR STATISTICS
KPRINT	FLAG FOR INDICATING PRINT FROM PB1A TO PRNTB1
KSECPR(4,17)	ARRAY OF STATISTICS SECTION FOR PRINTING
KTAB	NUMBER OF DATA POINTS ON SUMMARY TAPE
KTC	INDICATOR FOR INCLUSION OF TIME CORRECTION
LSFLAG	CONVERGENCE INDICATOR IN LEAST SQUARES
LTEMP	PACKED WORD OF STATION NUMBER AND DATA TYPES
LTEMP1	QUALITY BITS FOR OBSERVATION DATA - PACKED
MBATCH	INDICATOR FOR PRELIMINARY SECTION OF LEAST SQUARES
MXPASS	MAXIMUM VALUE OF PASS COUNTER IN LEAST SQUARES
NOISE	NOT PRESENTLY USED
NOFT	MAXIMUM NUMBER OF TIMES TO TRY CONVERGENCE IN LEAST SQUARES
NPASS	PASS COUNTER IN LEAST SQUARES
NT	COUNTER FOR TRYING CONVERGENCE IN LEAST SQUARES
NUM(26)	NUMBER OF DATA PTS TO SKIP BEFORE PROCESSING TYPE
PASS2	TOTAL NUMBER OF PASSES FOR SECOND TIME ARC
PAST	BCD WORD - ASTERISK - FOR AREJ ARRAY
PCOUNT	PRINT COUNTER IN LEAST SQUARES
PFLAG	INDICATOR FOR WHETHER A PRINT TIME
PSPACE	BCD WORD -BLANK - FOR AREJ ARRAY
REJCT1	SCALE FACTOR FOR STATISTICAL DATA REJECTION
REJCT2	SCALE FACTOR FOR STATISTICAL DATA REJECTION

RMEAN	STATISTICAL MEAN OF DISTRIBUTION - FOR FLORNG
RNGANS	NOT PRESENTLY USED
RNGFLG	FLOATING POINT VALUE OF IGUESS
RSIGMA	NOT PRESENTLY USED
SLUF	INDICATOR FOR FIRST TIME INTO RECORD PORTION OF MAINB1
STATYP(26)-INTEGER	PACKED WORDS, FOR EACH STATION, OF OBSERVATION TYPES STATION CAN MEASURE
TEBAR(4,4,26)	COVARIANCE MATRIX FOR EACH STATION
TEMP(4)	TEMPORARY VALUES FOR OBSERVATIONS

5.4 EXEC. B2 BLANK COMMON

5.4.1 DOUBLE PRECISION

Variable Name	Description
ALAM1(6,6)	UPPER LEFT OF STATE TRANSITION MATRIX
ALAM2(6,20)	UPPER RIGHT OF STATE TRANSITION MATRIX (LOWER 20X26=0,I)
ALMAT(26,6)	TEMPORARY MATRIX USED IN STATISTICS AND INTEGRATION
AUERAD	CONVERSION FACTOR-AU TO ER =23455.DO
BETA	DIFFERENTIAL ECCENTRIC ANOMALY
CDS(3)	REFERENCE FREQUENCIES USED IN DSIF SYSTEM
CKMER	CONVERSION FACTOR-ER TO KM =1.56784906D-4
CKSERH	CONVERSION FACTOR-ER/HR TO KM/SEC =.05644256616DO
COMB(5)	VELOCITY OF LIGHT PLUS 4 OPEN
CONST (25)	CONVERSION FACTORS FOR PRINTING OUT OBSERVATIONS
CPOS(6,7)	BLOCK OF REFERENCE BODY POSITIONS
CPRT(3)	CONSTANTS USED IN DSIF SYSTEM
CRAD	CONVERSION FACTOR- DEG TO RAD =.017453292519943DO
CVEL(6,7)	BLOCK OF REFERENCE BODY VELOCITIES
CZ	VALUE OF C AT RECTIFICATION POINT
D	NUMBER OF DAYS FROM O-HRS 1/1/50 TO PRESENT
DELALP(26)	VARIATION IN ALPHA PARAMETERS
DELTP	CURRENT PRINT INTERVAL WHEN NOT PROCESSING DATA
DELX(26)	VARIATION IN STATE VARIABLES
DELY(4)	ERROR IN OBSERVATIONS
DIN	NUMBER OF DAYS FROM O-HRS 1/1/50 TO O-HRS OF LAUNCH YEAR
DPADD(25)	ARRAY OF DOUBLE PRECISION VARIABLES
DT3(3,7)	RUNGE-KUTTA INTEGRATION INTERVALS FOR NEAR,MEDIUM AND FAR REFERENCE
DTI	CURRENT INTEGRATION INTERVAL
DTK	TIME INCREMENT USED FOR TIME CORRECTION
DTL	INCREMENT USED TO COMPUTE TL
DTP	INCREMENT USED TO COMPUTE TP
DYN(60)	ARRAY OF DYNAMIC STATES
DZ	VALUE OF D AT RECTIFICATION POINT
E	NUTATION IN OBLIQUITY
EBAR(4,4)	COVARIANCE MATRIX OF OBSERVATIONS
EF1	SUBSIDIARY OUTPUT FROM KEPLER
EF2	SUBSIDIARY OUTPUT FROM KEPLER
EF6	SUBSIDIARY OUTPUT FROM KEPLER
EF7	SUBSIDIARY OUTPUT FROM KEPLER
EMIN	MINIMUM ELEVATION ANGLE (RADIANS)
EPSSQ	SQUARE OF EARTH'S ELLIPTICITY =6.693422D-3
EQ	MEAN OBLIQUITY
ERAD	EARTH'S RADIUS IN KM = 6378.165DO
FRQ	REFERENCE FREQUENCY IN DSIF SYSTEM
GAM(3,3)	TRANSFORMATION MATRIX FROM ROTATING GEOCENTRIC SYSTEM TO INERTIAL SYSTEM
GAMM	GREENWICH HOUR ANGLE
GHA(3,3)	ORTHOGONAL TRANSFORMATION MATRIX
HMU	GRAVITATIONAL CONSTANT OF REFERENCE BODY
OBSPLS(9)	UNIT VECTORS DESCRIBING STATION-VEHICLE RELATIONSHIP
OLDT	PREVIOUS DTI

Variable Name	Description
ORM	MAGNITUDE OF THE POSITION VECTOR RCMSC
OVB(3)	VELOCITY VECTOR BETWEEN STATION AND VEHICLE
CVSB(3)	VELOCITY VECTOR OF STATION
PEROBL(3)	OBLATENESS PERTURBATION
PI	180 DEGREES IN RADIANS =3.141592653589793D0
PRENUT(3,5)	PRECESSION-NUTATION MATRIX
PREVTN	PREVIOUS VALUE OF TD
PRNT3(3)	PRINT INTERVALS FOR NEAR,MEDIUM AND FAR REFERENCE
PROPNL(3,3)	PRECESSION-NUTATION-LIBRATION MATRIX
PSI	NUTATION IN LONGITUDE
QSAVE(6,6)	SAVED PORTION OF UPPER LEFT OF Q MATRIX FOR LEAST SQUARES
R1(7)	DISTANCES IN ER FOR EACH OF 7 BODIES FOR SWITCHING FROM NEAR TO MEDIUM INTEGRATION INTERVALS
R2(7)	DISTANCES IN ER FOR EACH OF 7 BODIES FOR SWITCHING FROM MEDIUM TO FAR INTEGRATION INTERVALS
RA	RECIPROCAL OF SEMI-MAJOR AXIS OF ORBIT
RADII(7)	RADIUS OF EACH OF 7 WORKING BODIES (ER)
RATEV(3,2)	ROTATION VECTORS USED IN MARS AND VENUS DRAG COMPUTATIONS
RC(6)	INSTANTANEOUS POSITION VECTOR
RCIN(3)	INITIAL POSITION VECTOR
RCMSC(3)	POSITION VECTOR OF VEHICLE WITH RESPECT TO STATION
RDC(6)	INSTANTANEOUS VELOCITY VECTOR
RDCIN(3)	INITIAL VELOCITY VECTOR
RDDOT(3)	PERTURBATIONS OF COWELL INTEGRATION
RDI(6)	VELOCITY VECTOR AT LAST RECTIFICATION
RDTB(6)	TWO-BODY VELOCITY VECTOR
RI(6)	POSITION VECTOR AT LAST RECTIFICATION
RT1	VALUE USED AS TOLERANCE IN RECTIFICATION CRITERIA
RT2	VALUE USED AS TOLERANCE IN RECTIFICATION CRITERIA
RTB(6)	TWO-BODY POSITION VECTOR
SAVD	SAVED VALUE OF DTI
SAVEL1(6,6)	TEMPORARY MATRIX USED IN STATISTICS
SAVEL2(6,26)	TEMPORARY MATRIX USED IN STATISTICS
SCALE(3)	ARRAY OF SCALE FACTORS FOR PRINTING TRAJECTORY INFORMATION
SEC	SECONDS OF LAUNCH MINUTE
SMAT(6,6)	S OR S-INVERSE MATRIX - ALSO TEMPORARY MATRIX
SQTMU	SQUARE ROOT OF HMU
STAC(3)	CURRENT STATION COORDINATES
STAHT(26)	ARRAY OF STATION ALTITUDES
STALN(26)	ARRAY OF STATION LONGITUDES
STALT(26)	ARRAY OF STATION LATITUDES
STAOR(442)	ARRAY OF STATION-ORIENTED STATES
STATE(20)	VALUES OF NOMINAL STATES OF BIASES (NDSVB OF THEM)
T	CURRENT TIME (HRS)
TB	NUMBER OF JULIAN CENTURIES FROM 0-HRS 1/1/50 TO BASE DATE
TBF	F COEFFICIENT IN ENCKE COMPUTATION
TBFD	F DOT COEFFICIENT IN ENCKE COMPUTATION
TBG	G COEFFICIENT IN ENCKE COMPUTATION
TBGD	G DOT COEFFICIENT IN ENCKE COMPUTATION
TD	NEXT ACTIVITY TIME
TH	DIFFERENTIAL ECCENTRIC ANOMALY (ESTIMATE)
TI	TIME OF LAST RECTIFICATION
TIN	INITIAL TIME OF PASS

Variable Name	Description
TK	DATA POINT TIME MODIFIED BY TIME CORRECTION
TKEP	TIME OF KEPLER REFERENCE
TKRAW	DATA POINT TIME OFF DATA TAPE
TL	INTERMEDIATE TIME OF EXIT FROM COWELL INTEGRATOR
TMAX	CURRENT MAXIMUM TIME
TMAX2	MAXIMUM TIME OF SECOND TIME ARC
TMAXX	UPPER TIME LIMIT FOR RUN
TOLSQ	SQUARE OF TOLERANCE OF CONVERGENCE IN LEAST SQUARES
TP	PRINT TIME
TPMAT (3,3)	TEMPORARY MATRIX
TPMAT1(3,3)	TEMPORARY MATRIX
TPMAT2(3,3)	TEMPORARY MATRIX
TPMAT4(6)	TEMPORARY MATRIX
TPMAT5(6)	TEMPORARY MATRIX
TPMAT6(6)	TEMPORARY MATRIX
TPMAT7(6)	TEMPORARY MATRIX
TPMAT8(25)	TEMPORARY MATRIX
TPMAT9(21)	TEMPORARY MATRIX
TPRELM	MAXIMUM TIME OF PRELIMINARY BATCH IN LEAST SQUARES
TSPAN(6)	ARRAY OF TIME SPANS FOR EACH BATCH IN LEAST SQUARES
TSUBM	NEXT PRINT TIME
TSUBN	EARLIEST OBSERVATION TIME
TSVT(6)	ARRAY OF TEST TIMES
TTMAT1(3,3)	NUTATION MATRIX
TTMAT3(3,3)	PRECESSION MATRIX
TWOPI	360 DEGREES IN RADIANS =6.283185307179586D0
TX	TEMPORARY STORAGE OF INITIAL TIME
TY	TEMPORARY STORAGE OF FINAL TIME
TZEPH	NUMBER OF HRS FROM BEGINNING OF LAUNCH YEAR TO LAUNCH TIME
TZHRS	NUMBER OF HOURS FROM O-HRS 1/1/60 TO LAUNCH TIME
WE	EARTH ROTATION RATE
XC	MEAN LONGITUDE OF DESCENDING NODE OF MOON'S MEAN EQUATOR
XFAC	ARGUMENT OF SERIES EXPANSION IN TWO-BODY SOLUTION
XM(3,3)	LIBRATION MATRIX
XNCY	NUMBER OF CYCLES
XO	MEAN LONGITUDE OF THE MOON
YCOM(25)	ARRAY OF COMPUTED VALUES OF OBSERVATIONS
YOBS(25)	OBSERVED VALUES OF OBSERVATIONS
YOBSNU	CONSTANT = 1.D10 FOR OBSERVATION TESTS
YRTEMP(6)	TEMPORARY STORAGE IN OBSERVATION COMPUTATIONS
YTEMP(2)	TEMPORARY STORAGE IN OBSERVATION COMPUTATIONS

5.4.2 SINGLE PRECISION

AMUD	INDICATOR WHOSE VALUE REPRESENTS A CERTAIN ERROR CONDITION
AREJ(25)	OBSERVATION REJECTION INDICATORS FOR SUMMARY TAPE
BMAT(25,2)	SINGLE PRECISION OBSERVATIONS FOR SUMMARY TAPE
C1TAB(3)	CONSTANTS ASSOCIATED WITH RANGE-RANGE RATE SYSTEM
C2TAB(4,2)	CONSTANTS ASSOCIATED WITH RANGE-RANGE RATE SYSTEM
C3TAB(4)	CONSTANTS ASSOCIATED WITH RANGE-RANGE RATE SYSTEM
CDT(40)	TABLE OF DRAG COEFFICIENTS
CEPID	INDICATOR FOR COWELL OR ENCKE INTEGRATION

Variable Name	Description
CLUE	INDICATOR IN TIME CORRECTION
CNT	INTEGRATION FLAG
DAREA	EFFECTIVE SURFACE AREA OF VEHICLE PERTAINING TO DRAG
DAREAS	SAVED VALUE OF DAREA
DATA(4)	TEMPORARY STORAGE OF OBSERVATION DATA
DATTYP(4)-INTEGER	THE OBSERVATION TYPES FROM THE DATA TAPE
DAYS	DAYS OF LAUNCH YEAR
DELP(6)	ARRAY OF VALUES OF REFRACTION BIAS OFFSETS
DELTA	ELEVATION ANGLE ERROR IN REFRACTION
DH1	REFRACTION INCREMENT IN TROPOSPHERE (KM)
DH2	REFRACTION INCREMENT IN IONOSPHERE (KM)
DTPI	PRINT PORTION (HRS) OF TOTAL PRINT PERIOD
EBRMLT(4,26)	MODIFIERS FOR DATA COVARIANCE MATRIX FOR STATIONS
EBRVAL(4)	EBRMLT FOR THE CURRENT STATION
F1	UP FREQUENCY OF TRACKING SIGNAL
F2	DOWN FREQUENCY OF TRACKING SIGNAL
FDOWN(26)	ARRAY OF STATION RECEIVER FREQUENCIES
FIRST	INDICATOR FOR FIRST TIME THROUGH MAIN
FKPR	FLOATING POINT PRINT INDICATOR
FPK	INDICATOR FOR TIME DIRECTION ≡+1 - FORWARD IN TIME ≡-1 - BACKWARD IN TIME
FPIP	FLOATING PT IPS
FUP(26)	ARRAY OF STATION TRANSMITTER FREQUENCIES
H2	LOWER LIMIT OF IONOSPHERE (KM)
H4	UPPER LIMIT OF IONOSPHERE (KM)
HACC	ACCUMULATED ALTITUDE OF ITERATION IN REFRACTION
HMIN	MINUTES OF LAUNCH HOUR
HRS	HOURS OF LAUNCH DAY
I365	INTEGER ≡365
ICOUNT	COUNT NUMBER OF DATA POINT
ID	TIME DIRECTION INDICATOR ≡0 - TMAX > 0 ≡1 - TMAX < 0
IDER	INTEGRATION INDICATOR
IGUESS	CURRENT VALUE OF RANDOM NUMBER
IMODE	MODE
IMODES	SAVED VALUE OF IMODE
INPERR	INPUT ERROR INDICATOR
IOBLAT(26)	INDICATORS OF DESIRED OBLATENESS COEFFICIENTS (10N+M)
IP	INDICATOR OF NUMBER OF RUNGE-KUTTA STEPS
IPLNT	NUMBER OF PLANET TO BE USED FOR COMPUTING ONBOARD OBSERVA-TIONS
IPMAT	INPUT INDICATOR FOR READING P OR Q MATRIX
IPS	TIME DIRECTION INDICATOR =0 - TOWARD TMAX =1 - TOWARD 0
IPSEC(10)	INDICATORS FOR PRINTING TRAJECTORY INFORMATION
IPSS	SAVED VALUE OF IPS
IQZERO	INDICATOR FOR GROWN OR INPUT Q MATRIX
IRDATA	INDICATOR FOR DATA REJECTION
IRT	INDICATOR FOR BYPASSING INTEGRATION
ISTAR	NUMBER OF STAR TO BE USED FOR COMPUTING ONBOARD OBSERVATIONS

Variable Name	Description
ISTAT	INDICATOR FOR MINIMUM VARIANCE OR LEAST SQUARES
ISUMRY	INDICATOR FOR SUMMARY TAPE
ITER2	ITERATION INDICATOR
ITERS	INDICATOR FOR READING IN DATA TAPE
IXADD(25)	INTEGER ARRAY
JFLAG	EXIT INDICATOR FROM LEAST SQUARES
KCOM	INDEX OF CURRENT BIAS TYPE
KECLPS	INDICATOR FOR PRINTING ECLIPSE INFORMATION
KFLAG	INDICATOR FOR BATCH TYPE IN LEAST SQUARES
KLAST	INDICATOR FOR FINAL LEAST SQUARES BATCH
KLIBR	INDICATOR FOR LIBRATION OF VECTORS
KM(4)	UNPACKED STATYP ARRAY FOR CURRENT STATION
KOBLAT	NUMBER OF OBLATENESS COEFFICIENTS
KOMP	INDICATOR FOR CRITERION LEADING TO RECTIFICATION
KOMPS	SAVED VALUE OF KOMP
KOPT	PRINT OPTION INDICATOR FOR STATISTICS
KPRINT	FLAG FOR INDICATING PRINT FROM BPRA2 TO BPRB
KRF	INDICATOR FOR REFRACTION COMPUTATIONS
KS2BY	INDICATOR FOR TWO-BODY INTEGRATION ONLY
KSDRG	INDICATOR FOR EARTH DRAG PERTURBATION
KSDRGM	INDICATOR FOR MARS DRAG PERTURBATION
KSDRGV	INDICATOR FOR VENUS DRAG PERTURBATION
KSECPR(4,17)	ARRAY OF STATISTICS SECTION FOR PRINTING
KSMNOB	INDICATOR FOR MOON OBLATENESS PERTURBATION
KSNAP	INDICATOR FOR PRECESSION-NUTATION
KSOBL	INDICATOR FOR OBLATENESS PERTURBATIONS
KSPLT	INDICATOR FOR PLANETARY PERTURBATIONS
KSRAP	INDICATOR FOR RADIATION PRESSURE PERTURBATION
KSTA	CURRENT STATION NUMBER
KSTDRD	INPUT INDICATOR FOR STANDARD VALUES
KTAB	NUMBER OF DATA POINTS ON SUMMARY TAPE
KTC	INDICATOR FOR INCLUSION OF TIME CORRECTION
KWBMU(7)	ARRAY OF WORKING BODIES
LEVEL	NOT PRESENTLY USED
LSFLAG	CONVERGENCE INDICATOR IN LEAST SQUARES
LTEMP	PACKED WORD OF STATION NUMBER AND DATA TYPES
LTEMP1	QUALITY BITS FOR OBSERVATION DATA-PACKED
M5	INTEGER =5
M6	INTEGER =6
M20	INTEGER =20
M26	INTEGER =26
MAXLUN	MAXIMUM NUMBER OF LUNAR LANDMARKS
MAXSTA	TOTAL NUMBER OF STATIONS CONSIDERED
MBMAX	TOTAL NUMBER OF WORKING BODIES CONSIDERED
MCOL(20)	ARRAY OF CODE WORDS FOR BIASES
MFLAG	INDICATOR FOR COMPLETION OF A PASS
MINUS1	INTEGER =-1
MINUS2	INTEGER =-2
MPLUS1	INTEGER = 1
MPLUS2	INTEGER = 2
MPLUS3	INTEGER = 3
MPLUS4	INTEGER = 4
MRREF	SAVED VALUE OF INITIAL REFERENCE BODY

Variable Name	Description
MWREF	CURRENT REFERENCE BODY
MXPASS	MAXIMUM VALUE OF PASS COUNTER IN LEAST SQUARES
NA(4,26)	CTR USED IN DETERMINING ACCEPTANCE TIMES FOR DATA TYPES
NBST	TOTAL NUMBER OF BIASES + 6
NCDST	INDEX FOR STATION BEING PROCESSED
NCOMB	TOTAL NUMBER OF COMBINATION-TYPE BIASES
NCODE	TEMPORARY CODE WORD FOR BIAS TYPES
NDB	TOTAL NUMBER OF DYNAMIC BIASES
NDB1	NDB + 1
NCMB1	NCOMB + 1
NCSB	NCOMB + NSB
NCSB1	NCSB + 1
NDSVB	NDB + NSB + NCOMB
NOFT	MAXIMUM NUMBER OF TIMES TO TRY CONVERGENCE IN LEAST SQUARES
NOISE	NOT PRESENTLY USED
NPASS	PASS COUNTER IN LEAST SQUARES
NSB	TOTAL NUMBER OF STATION-ORIENTED BIASES
NT	COUNTER FOR TRYING CONVERGENCE IN LEAST SQUARES
NUM(26)	NUMBER OF DATA PTS TO SKIP BEFORE PROCESSING TYPE
NUMDAT	CURRENT NUMBER OF OBSERVABLES AT STATION
NUMT	COUNTER USED IN BPRB
NUT	INDICATOR FOR INITIAL TIME OF PASS
NYEARP	YEAR OF LAUNCH
OFFSET(20)	ARRAY OF VALUES OF DYNAMIC BIAS OFFSETS
OLDYR	NOT PRESENTLY USED
ONE	FLOATING POINT=1.0
PAREA	EFFECTIVE SURFACE AREA OF VEHICLE PERTAINING TO RADIATION PRESSURE
PAREAS	SAVED VALUE OF PAREA
PARTD(6)	ARRAY OF PARTIALS OF ELEVATION WITH RESPECT TO THE 6 REFRACTION PARAMETERS
PARTR(6)	ARRAY OF PARTIALS OF RANGE WITH RESPECT TO THE 6 REFRACTION PARAMETERS
PARTRR(6)	ARRAY OF PARTIALS OF RANGE RATE WITH RESPECT TO THE 6 REFRACTION PARAMETERS
PASF	TOTAL NUMBER OF PASSES FOR FIRST TIME ARC
PASFX	SAVED VALUE OF PASF
PASS	CURRENT PASS NUMBER
PASS2	TOTAL NUMBER OF PASSES FOR SECOND TIME ARC
PAST	BCD WORD - ASTERISK - FOR AREJ ARRAY
PCOUNT	PRINT COUNTER IN LEAST SQUARES
PFLAG	INDICATOR FOR WHETHER A PRINT TIME
POSLUN(2,10)	LUNAR POSITION TABLE NEEDED BY SUBROUTINE ONBRD
PRATE	INDICATOR FOR PRINT PERIOD
PRECIS	INDICATOR FOR PRECISION LEVEL
PSPACE	BCD WORD- BLANK- FOR AREJ ARRAY
PVALPH(3)	BCD ARRAY FOR PRINTING OUT PROPER UNITS
REJCT1	SCALE FACTOR FOR STATISTICAL DATA REJECTION
REJCT2	SCALE FACTOR FOR STATISTICAL DATA REJECTION
RMEAN	STATISTICAL MEAN OF DISTRIBUTION - FOR FLORNG
RNGFLG	FLOATING POINT VALUE OF IGUESS
RSIGMA	NOT PRESENTLY USED

Variable Name	Description
RTO	RATIO OF NORDSIECK INTEGRATION INTERVAL TO THAT IN RUNGE-KUTTA
SIXTY	FLOATING POINT =60.0
SLUE	INDICATOR FOR FIRST TIME INTO RECORD PORTION OF B2MAIN
SPADD(25)	SINGLE PRECISION ARRAY
STANM(26)	ARRAY OF STATION NAMES
STAR(2,10)	STAR TABLE NEEDED BY SUBROUTINE ONBRD
STATYP(26)-INTEGER	PACKED WORDS FOR EACH STATION OF OBSERVATION TYPES STATION CAN MEASURE
SUMCOM(3)	ARRAY OF CONSTANTS
T1(6)	THE 6 REFRACTION PARAMETERS
TAU	PRINT INDICATOR
TEBAR(4,4,26)	COVARIANCE MATRIX FOR EACH STATION
TDELAY(4,26)	TIME (HRS) BEFORE WHICH OBSERVATION IS NOT TO BE COMPUTED
TEMP(4)	TEMPORARY VALUES FOR OBSERVATIONS
THREE	FLOATING POINT =3.0
TWO	FLOATING POINT =2.0
TWT4	FLOATING POINT =24.0
TYPE(26)-INTEGER	ARRAY OF OBSERVATION TYPES DESIRED - PACKED
TZERO	LAUNCH TIME IN HOURS
USETYP(4)-INTEGER	UNPACKED TYPE ARRAY FOR CURRENT STATION
VMASS	MASS OF VEHICLE
XLST	LOCAL SOLAR TIME USED IN DRAG COMPUTATION
XKN	TOTAL NUMBER OF HOURS IN THE LAUNCH YEAR
XMACH(40)	TABLE OF MACH NUMBERS
XNNEW	CURRENT INDEX OF REFRACTION
YEAR	FLOATING POINT NYEARP

5.5 EXECB2 Labelled Common

/CSTAT/		SUBROUTINES BYSB2, STTB2, B2INPT, BPRB
STAT(26,26)	-D.P.-	COMPLETE Q MATRIX (STATISTICS)
/D1/		ENCKE SUBROUTINES-EB2DER, EBITG, EBNT
CWLIN(9,21)	-S.P.-	PERTURBATIONS AND 1ST AND 2ND DERIVATIVES FOR NOMINAL AND BIASES - (ENCKE INTEGRATIONS)
/CBD/		COWELL SUBROUTINES-CB2DER, CBNT
RAT(3,21)	-D.P.-	2ND DERIVATIVE OF PERTURBATION FOR NOMINAL AND BIASES (COWELL INTEGRATIONS)

6.0 Subroutine Descriptions

The subroutine descriptions which follow provide details of the individual subroutines. The descriptions are organized according to the following outline.

X. Subroutine DUMMY (ARG1, ARG2)

X.1 Purpose

X.2 Method

X.3 Program References

X.3.1 DUMMY is called by:

X.3.2 DUMMY calls:

X.4 I/O Data*

X.4.1 Inputs from COMMON

X.4.2 Outputs to COMMON

X.4.3 Other Inputs

X.4.4 Other Outputs

X.5 Symbols Used*

X.5.1 COMMON Symbols

X.5.2 Other Symbols (Including Definitions)

X.6 Equations Used

X.7 Flow Diagram

* Variables are listed in two groups, alphabetically. The first group is double precision, the second group is single precision.

The subroutines which are described and the sub-programs which use subroutines are as follows:

X Subroutine	EXEC A	EXEC B1	EXEC B2	X Subroutine	EXEC A	EXEC B1	EXEC B2
1. ATIM	X			24. EXECA	X	-	-
2. CCHREF	X	X		25. FIX	X	X	X
3. CDERIV	X	X		26. INPUTA	X		
4. CINT	X	X		27. KEPLER	X	X	
5. CINTRP	X	X		28. MAINA	X		
6. CITGRA	X	X		29. MODELA	X	X	
7. CMNOBP	X	X		30. NUTPRE	X	X	
8. CMVDRG	X	X		31. OBD	X		
9. COBDRG	X	X		32. OBSERA	X		
10. *CRSTRE	X	X		33. PFINIT	X	X	
11. DDOT	X	X	X	34. PFLGHT	X	X	
12. DMTML	X	X	X	35. PRINTA	X		
13. DOMUD	X	X		36. RECT	X	X	
14. ECHREF	X	X		37. SERVCE	X	X	X
15. EDERIV	X	X		38. STACUL	X	X	
16. EINT	X	X		39. STAPOS	X	X	
17. EINTRP	X	X		40. TIMNGA	X		
18. EITGRA	X	X		41. XFORM	X	X	
19. EMNCBP	X	X		42. BAYSB1		X	
20. EMVDRG	X	X		43. DALFA		X	
21. EOBDRG	X	X		44. EXECB1		X	
22. EPHEM	X	X		45. FLORNG	X	X	X
23. *ERSTRE	X	X		46. INPTB1		X	

*The function of storing and re-storing provided by these routines is not used in EXECB1. Therefore, they can be replaced by dummies or removed. They are presently retained as dummies to maintain similar integration packages in the A and B1 sub-programs.

X Subroutine	EXEC A	EXEC B1	EXEC B2
47. MAINB1		X	
48. MATINV	X	X	X
49. OBSRB1		X	
50. ONOBS		X	
51. ONPTL		X	
52. PASMB1		X	
53. PB1A		X	
54. PRNTB1		X	
55. PTB1		X	
56. PTLSB1		X	
57. REWIN		X	X
58. SBSRB1		X	
59. SNOBS		X	
60. SNPTL		X	
61. STATB1		X	
62. STLSB1		X	
63. SUMARY		X	X
64. SYMMAT		X	X
65. B2BOB			X
66. B2BITG			X
67. B2EPHM			X
68. B2EXEC			X
69. B2INPT			X

X Subroutine	EXEC A	EXEC B1	EXEC B2
70. B2KEP			X
71.A B2MAIN			X
71.B B2MAIN			X
72. B2NUT			X
73. B2OBOS			X
74. B2OCOL			X
75. B2ONPL			X
76. B2PASM			X
77. B2PLST			X
78. B2RECT			X
79. B2STOB			X
80. BPRA2			X
81. BPRB			X
82. BPTA2			X
83. BPTLS			X
84. BYSB2			X
85. CB2DER			X
86. CBCHRF			X
87. CBITG			X
88. CBMNOB			X
89. CBMVDG			X
90. CBNT			X
91. CBOBDG			X

	X Subroutine	EXEC A	EXEC B1	EXEC B2
92.	DLFB2			X
93.	DMUDB2			X
94.	EB2DER			X
95.	EBCHRF			X
96.	EBITG			X
97.	EBMNOB			X
98.	EBMVDG			X
99.	EBNT			X
100.	EBOBDG			X
101.	MDLB2			X
102.	OBBSR			X
103.	STPSB2			X
104.	STTB2			X
105.	XFRMB2			X

Many of the subroutines in the EXECB2 sub-program are equivalent to the corresponding subroutines in the A and B1 sub programs. New names were assigned to equivalent subroutines for two reasons:

1. COMMON is different between EXECB1 and EXECB2.
2. Subroutines called by a B2 subroutine may have different names then those in the equivalent B1 subroutine.

7.0 References

Ref. 1. Analytical Manual for Goddard Orbit Determination Program, Sperry Gyroscope Report No. AB-1210-0038, April 1965.

Ref. 2. Users Manual for Goddard Orbit Determination Program, Sperry Gyroscope Report No. AB-1210-0038-2, April 1965.

1. Subroutine ATIM

1.1 Purpose

This subroutine is used in the prediction mode A4. It will determine the exact time the vehicle comes within sight of a given station. The time of polar base line and meridian crossings are also calculated.

1.2 Method

When NEL $\geq$ 0, the vehicle is in sight and only the l and m direction cosines are to be tested to determine the time of polar and meridian crossings.

When NEL $<$ 0, the acquisition time is to be determined. This is the exact time the vehicle comes over the horizon with respect to a particular ground station. The vehicle is considered in sight when the elevation angle is greater than some inputted value (EMIN). The time is exact to within an inputted delta (DSPL).

1.3 Program References

1.3.1 ATIM is called by:

OBSERA

1.3.2 ATIM calls:

CINT, CRSTRE, EINT, ERSTRE, KEPLER

1.4 I/O Data

1.4.1 Inputs from COMMON

DSPL, DTI, EMIN, OLEL, RDTB, RTB, SAVD, SVL, SVM, T, [illegible]SSA, [illegible]
CEPID, KS2BY, MPLUS1, MPLUS2, NEL, USETYP

1.4.2 Output to COMMON

DTI, RC, RDC, TAQ
NEL

1.4.3 Other Inputs

None

1.4.4 Other Outputs

TPEL - time of meridian crossing

TPEM - time of polar base line crossing

1.5 Symbols used other than COMMON

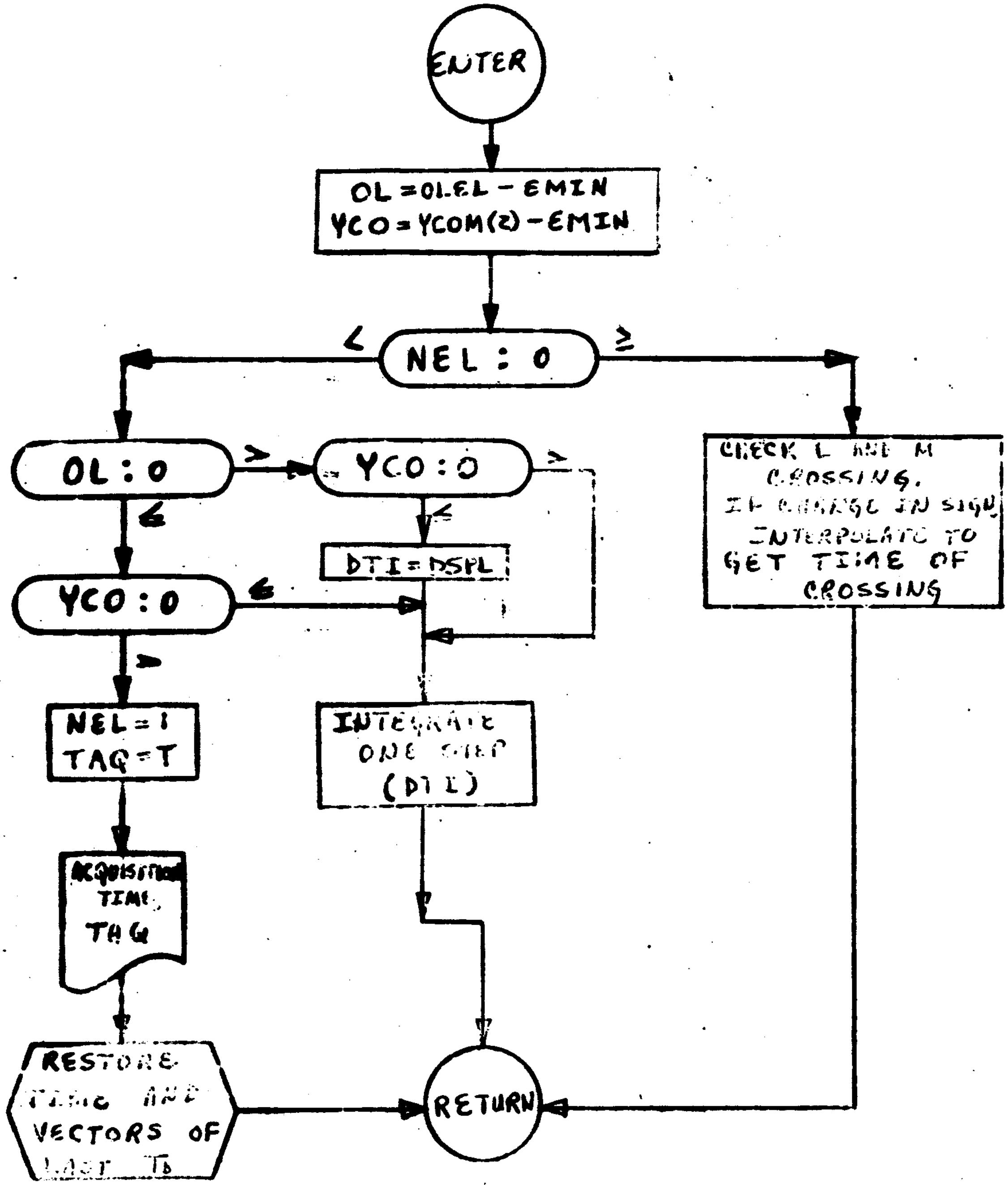
OL = OIEL - EMIN
YCO=ECOS(2) - EMIN

1.6 Equations used

Interpolation formula to determine time of crossings

$$T_{\text{of crossing}} = T - \left[\frac{\text{Saved direction cosine} \times (T_{\text{present}} - T_{\text{saved}})}{\text{Present direction cosine} - \text{saved direction cosine}} \right]$$

1.7 FLOW DIAGRAM - ATIM



2.1 Purpose

This subroutine tests criteria for changing of the reference body when the Cowell integrator is used. Even though a change of reference body in the Cowell method is not necessary, it is utilized in the program in the same manner as in the Encke integrator.

2.2 Method

The criteria for reference body change depends upon the location of the vehicle with respect to the planetary bodies. If within 12 E.R. of the moon, the program computes the effective radius of activity for the earth-moon system in the region where the vehicle lies. If not within 12 E.R. of the moon but within the sphere of influence of any one of the planets, it tests the vehicle' distance from the reference body center against the radius of activity of the particular planet. When in sun reference, it tests to determine if the vehicle has entered the region of influence of any one of the planets. Upon determining that a transfer is indicated, flags are set so that the position and velocity vectors of the vehicle are translated to be with respect to the new reference body.

2.3 Program References

2.3.1 CCHREF is called by:

CITGRA

2.3.2 CCHREF calls:

DOCT, EPHEM, SERVCE

2.4 I/O Data

2.4.1 Inputs from COMMON

CPOS, CVEL, DPADD(1), DPADD(10), DT3, RC, RDC
KWBMU, MBMAX, MPLUS1, MPLUS2, MPLUS3, MWREF, ONE

2.4.2 Outputs to COMMON

DPADD(1-7), DT3, RC, RDC, T
KOMP, MWREF

2.5 Symbols Used

2.5.1 COMMON symbols

TPMAT4, TPMAT5, TPMAT6, TPMAT7, TPMAT8

2.5.2 Other symbols

RACT(7) - radius of activity for each of 7 bodies

RMAGF - open function to compute magnitude of a vector

INDX - index denoting reference body

ISW - index used in earth-moon reference

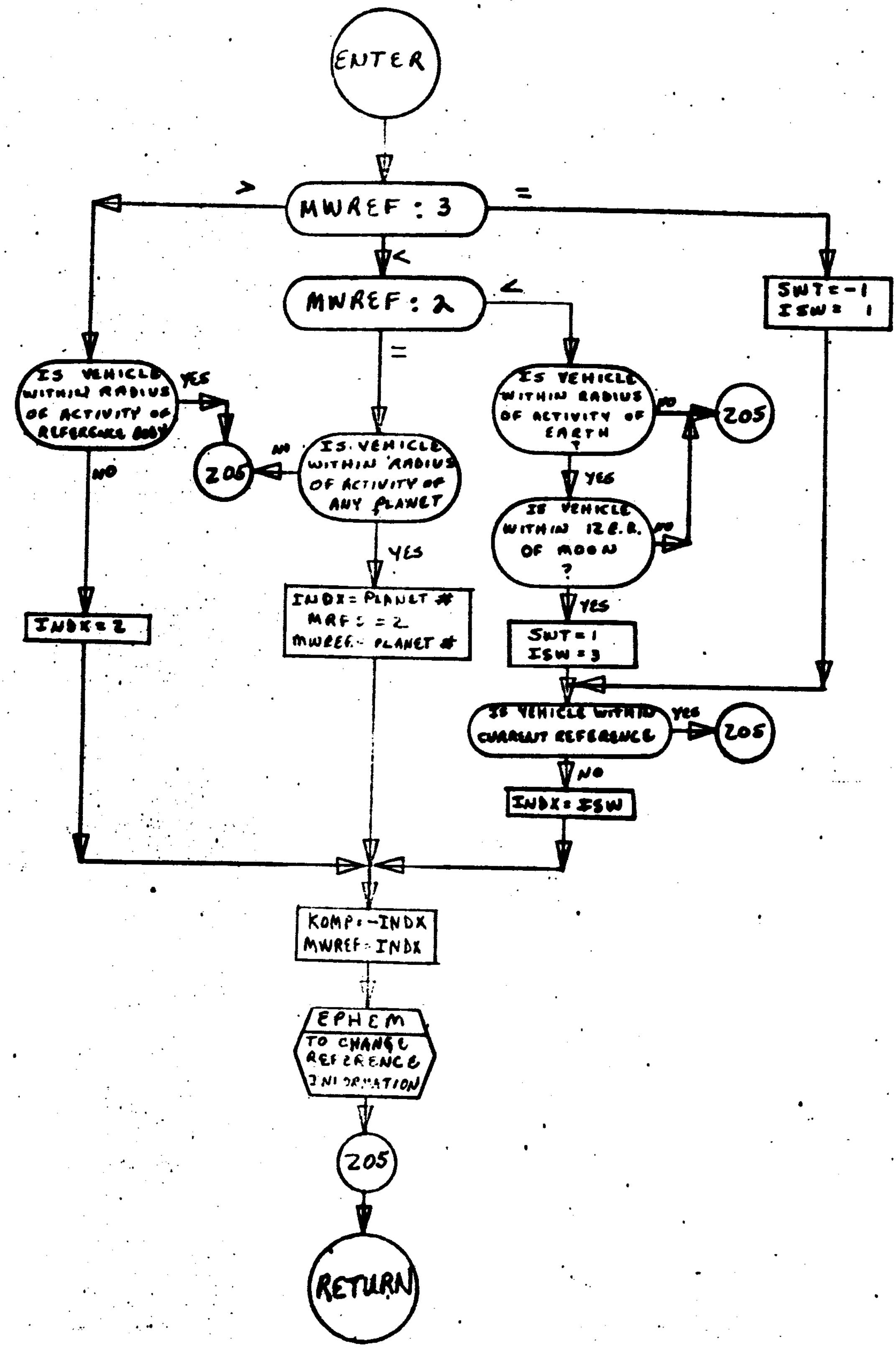
MRFS - saved MWREF

SWT - switch used in earth-moon reference

2.6 Equations Used

See Ref. 1, Section 3.5.

2.7 FLOW DIAGRAM - COHREF



3. Subroutine CDERIV

3.1 Purpose

This subroutine evaluates the acceleration terms for the Cowell integrator. There are two versions to this routine. The maximum version includes radiation pressure acceleration terms and can print eclipse information. In the minimum version, these computations are eliminated.

3.2 Method

The subroutine computes the planetary perturbations, powered flight accelerations, and the solar radiation pressure perturbations. Earth oblateness and drag are computed in the subsidiary subroutine COBDRG, lunar oblateness accelerations in CMNOBP, and the drag of Mars and Venus atmosphere in CMVDRG.

3.3 Program References

3.3.1 CDERIV is called by:

CINT

3.3.2 CDERIV calls:

CMNOBP, CMVDRG, COBDRG, DDOT, DOMUD, EPHEM, SERVCE

3.4 I/O Data

3.4.1 Inputs from COMMON

3.4.1.1 CPOS, DYN, PEROBL, PFPAR, RC, RDC,
IPFT, KSDRG, KSPLT, KWBMU, MBMAX, MPLUS2, MPLUS3,
MWREF, PFON, THREE, TWO

3.4.1.2 Radiation pressure portion only

DPADD(11-15), DYN, T, TWOPI
IXADD(1-4), KECLPS, KSRAP, MPLUS1, ONE, RADII

3.4.2 Outputs to COMMON

3.4.2.1 RDDOT

3.4.2.2 Radiation Pressure portion only

DPADD(11-15), DYN
IXADD(1-4)

3.5 Symbols Used

3.5.1 COMMON Symbols - used only in Radiation Pressure Portion.

TPMAT2, TPMAT4, TPMAT5, TPMAT6, TPMAT7, TPMAT8, TPMAT9

3.5.2 Other Symbols

3.5.2.1 DU - temporary solution used in computing planetary acceleration

ENKEF - open function to compute planetary accelerations

SDDXI(3) - temporary storage of planetary (and pressure) acceleration

SRVB(3) - vector from vehicle to perturbing body.

U(3) - temporary solutions used in computing planetary accelerations.

N - index for current working body

PLANT1 - BCD word = PLANET

3.5.2.2 Radiation Pressure Portion only

TC - time of crossing into moon umbra, umbra, sunlight or penumbra.

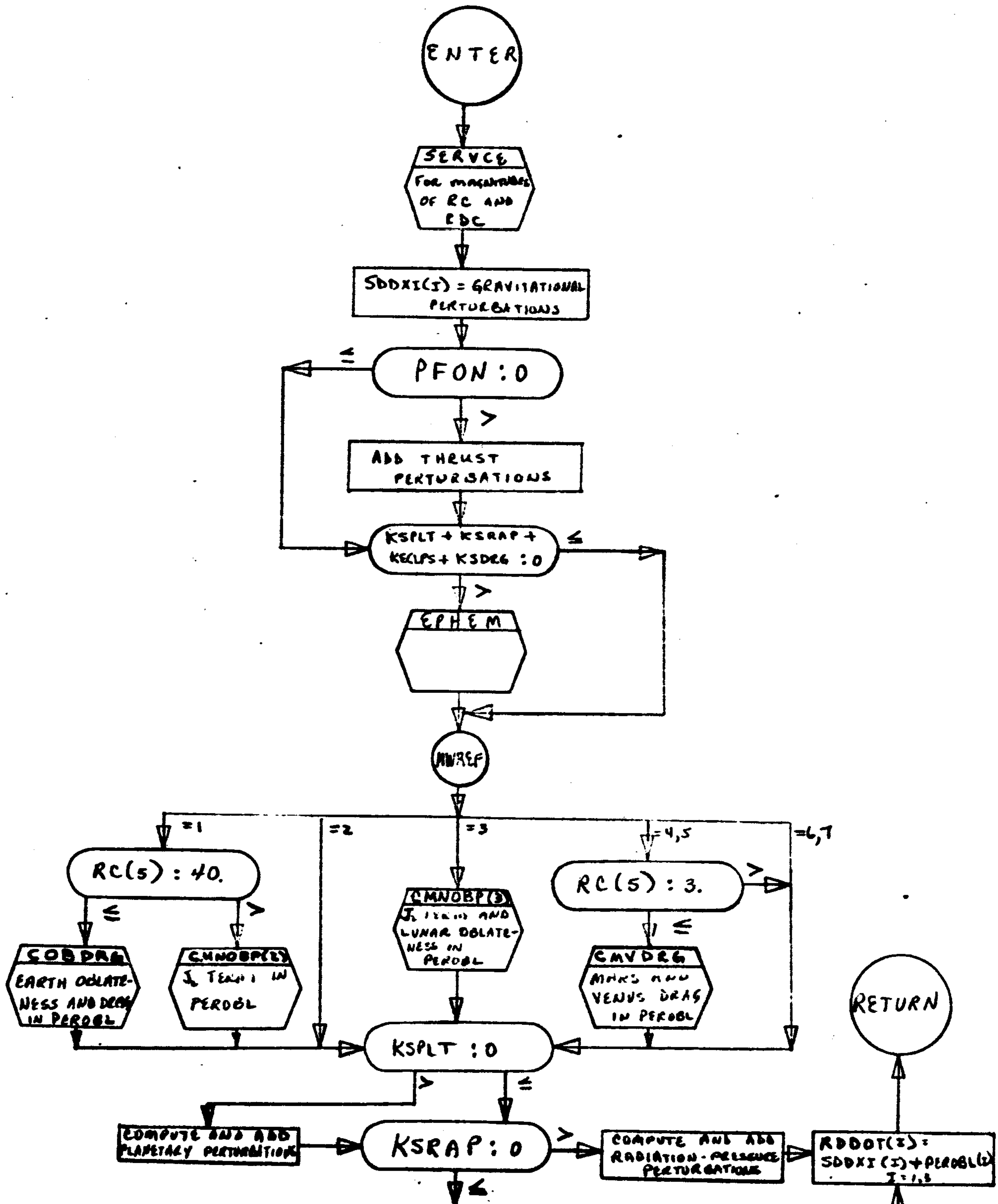
IEC, ILUM, IPEN, IREF, ITWICE, JIM, JOAN - flags

XK - factor describing foreshortening of umbral cone due to bending of light rays traveling through the atmosphere.

3.6 Equations Used

See Ref. 1, Section 4.

3.7 FLOW DIAGRAM - CDERTV



4. Subroutine CINT (IENT)

4.1 Purpose

This subroutine is the Cowell integrator. Runge-Kutta integration is used for short time integration and to start the Nordsieck long time integrations.

4.2 Method

When IENT = 1, a normal integration step using the Nordsieck method is taken. This method is not self-starting. A table of six previous time steps must be formed. The initialization is done by taking Runge-Kutta steps.

When IENT = 2, only a Runge-Kutta integration step is taken.

When IENT = 3, the delta of integration is changed. When in Nordsieck integration, the stored time table must be adjusted.

Double precision solution of accelerations is used throughout.

4.3 Program References

4.3.1 CINT is called by:

ATIM, CITGRA

4.3.2 CINT calls:

CDERIV

4.4 I/O Data

Inputs from COMMON.

DTI, OLDT, RC, RDC, RDDOT, T
IP, MPLUS1, MPLUS2, MPLUS4, ONE, RTO, THREE

4.4.2 Outputs to COMMON

RC, RDC, T
IP

4.4.3 Other Inputs

IENT

4.4.4 Other Outputs

None

4.5 Symbols Used Other Than COMMON

BRG(5,6) - Adjusted values of velocity and acceleration of the last six integration steps

CON(5,6) - (Data) matrix of constants for Nordsieck Integrator

DIFFY - Difference between the prediction and exact value of variables to be integrated

H - Delta of integration

QT(6) - Runge-Kutta Integration multiplier

RKA(4) - (Data) Runge-Kutta constants

RKB(4) - (Data) Runge-Kutta constants

RKC(4) - (Data) Runge-Kutta constants

RKFT - Temp storage for Runge Kutta Integrator

RKT(4) - (Data) Runge-Kutta constant

RPY(6) - Temporary matrix of velocity and acceleration vectors for Runge-Kutta integration

RPYN(6) - Predicted velocity and acceleration vectors for Nordsieck integration

RY(6) - Temporary matrix of position and velocity vectors for Runge-Kutta integration

TQU - Runge-Kutta integration multiplier

XK(6) - (Data) Nordsieck constant

XX - Not used

Y(6) - Temporary matrix of position and velocity for Cowell integrator

YIP(6) - Temporary matrix of velocity and acceleration for Cowell integration

YP(6,6) - Saved velocity and acceleration terms of six Runge-Kutta steps

YR - Temporary variable

BET - Ratio between Nordsieck and [redacted]egration step size

BETT - Temporary storage

COEF(11) - (Data) constants for Nordsieck integration

CTI - Temporary storage

IGT - Flag

MB - Temporary counter

KI - Temporary counter

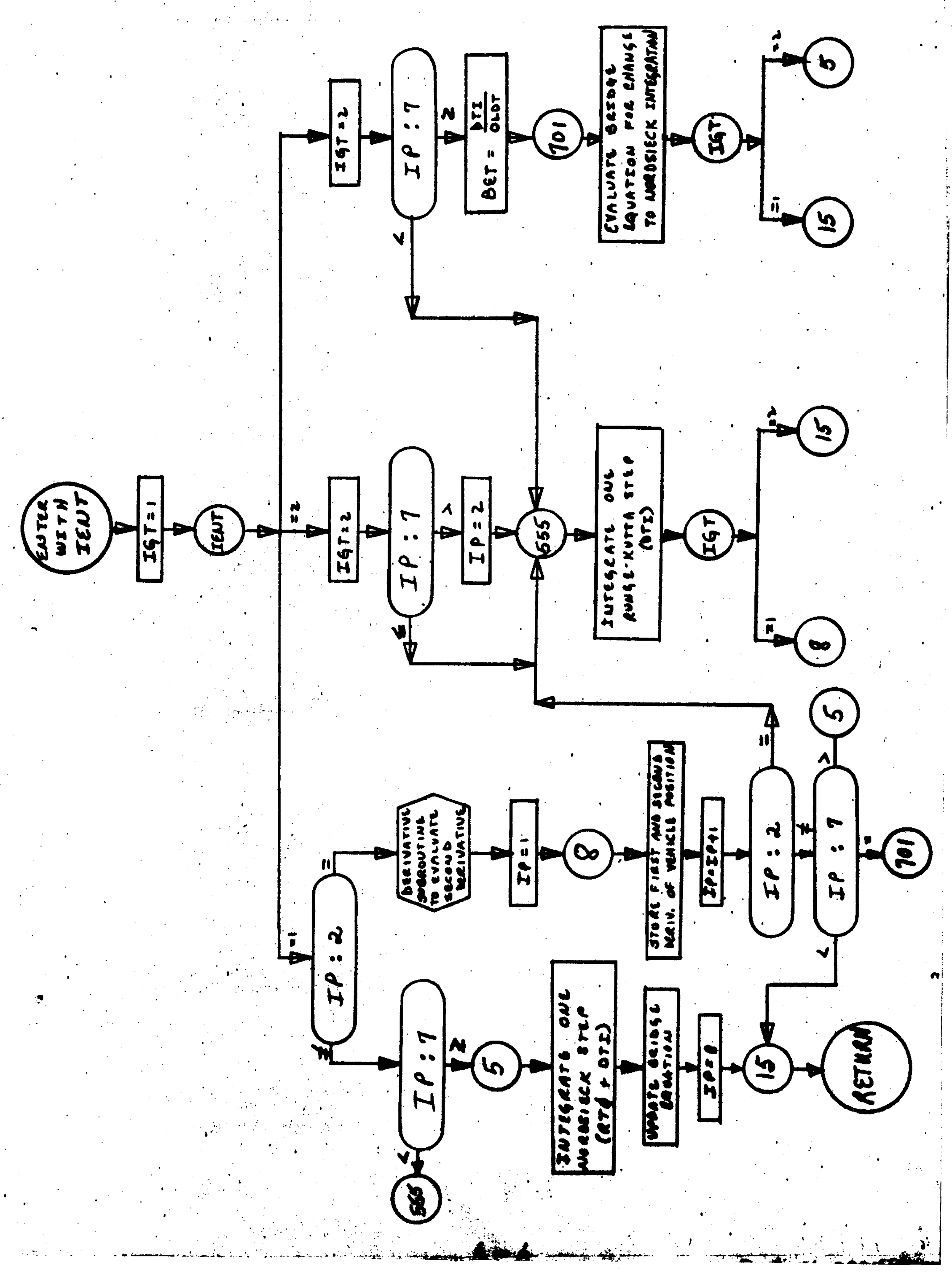
4.6 <u>Equations Used</u>

Runge-Kutta Gill method of integration

Nordsieck method of integration

See Ref. (1), Section 3.2.3

4.7 FLOW DIAGRAM - CINT



5. Subroutine CINTRP (X1, X2, X3, GV, DRAGHI)

5.1 Purpose

This subroutine evaluates the density of air as obtained from high atmosphere drag tables.

5.2 Method

Drag tables are stored in this routine along with a routine for interpolating within the tables. A separate subroutine (COBDRG) calls this routine. This routine does not contain COMMON since the lengthy data plus COMMON overload certain compilation limitation set by FORTRAN IV.

5.3 Program References

CINTRP is called by:

COBDRG

5.4 I/O Data

5.4.1 Inputs

X1 - Altitude of vehicle

X2 - solar flux

X3 - local solar time

5.4.2 Outputs

GV - Log of air density interpolated from table. It is computed by linear interpolation from the drag table (TDENHI) corresponding to twilight.

DRAGHI - Interpolated value of density from Harris-Priester high altitude drag tables (DENHI)

5.5 Symbols Used

AL(3) - the 3 inputs in array form

H(1) - altitude of vehicle normalized to values in log tables

H(2) - solar flux at input normalized to values in log tables

H(3) - local solar time at input normalized to values in log tables

DENHI(16,4,3) - Harris-Priester density tables (Data)

*IAL(I) - temporary matrix

IALT - equivalence IAL(1)

*IJ(I) - (Data) set of indices used for interpolating

*IK(I) - (Data) set of indices used for interpolating

ILST - equivalence IAL(3)

ISF - equivalence IAL(2)

TDENHI(16,4) - table of densities at twilight (Data)

TABLE (33) - general table used to control interpolation (Data)

*I = 1, altitude

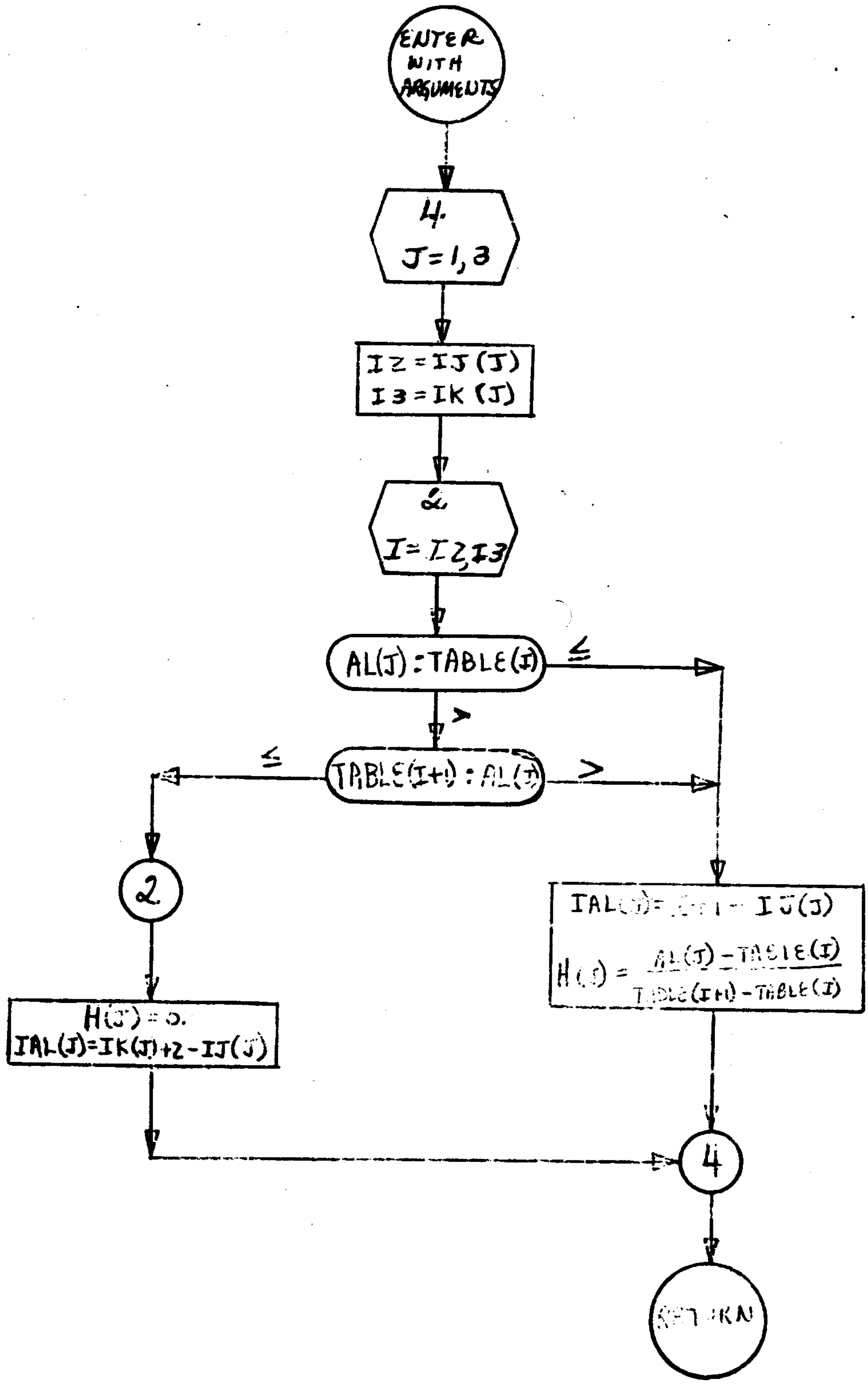
= 2, solar flux

= 3, local solar time

5.6 Equations Used

Linear interpolation in tables. See Ref. 1, Section 4.

5.7 FLOW DIAGRAM - CINTRP



6. Subroutine CITGRA

6.1 Purpose

This subroutine serves as the sub-main program governing calls to the integration subroutines in the Cowell method.

6.2 Method

The program first checks to see if in powered flight. If not, it checks to see whether to change reference. Depending on position, the delta of integration and printing are determined and integration is performed up to TD. If the TD is not a normal integration step, the time, position and velocity vectors of the last integration step are saved and integration is performed up to the time, TD.

6.3 Program References

6.3.1 CITGRA is called by:

A - MAINA
B1 - MAINB1

6.3.2 CITGRA calls:

CCHREF, CINT, CRSTRE

6.4 I/O Data

6.4.1 Inputs from COMMON

DT3, PFPAR, PRNT3, R1, RG, T, TD, TL
FPK, IDER, IP, IPFT, KOMP, LML, MPLUS1, MPLUS2, MPLUS3, MUREF, ONE, PFON, PURP, RTO, THREE

6.4.2 Outputs to COMMON

DELTP, DTI, OLDT, SAVD, T
CNT, IDER, IP, KOMP, TSTRO

6.5 Symbols Used

6.5.1 COMMON Symbols

SAVD - Saved DTI

6.5.2 Other Symbols

EDT - special integration step size

TSTTM - difference in time between next integration time (TTEMP) and the time of interest (TD).

TTEMP - next integration time

TRF - distance indicator, determining when to check for reference change

6.6 Equations Used

None

6.7 Flow Diagram

See EITGRA (18.7) with no test for rectification.

7. Subroutine CMNOBP (K)

7.1 Purpose

This subroutine computes the acceleration due to lunar oblateness. Optionally, it can compute the libration and the effect of the earth's J_{20} term, for Cowell integration.

7.2 Method

When K = 1, the libration matrix is computed and then precessed and nutated.

When K = 2, the earth's J_{20} oblateness term is calculated.

When K = 3, both lunar and earth oblateness (J_{20} term) are computed.

7.3 Program References

7.3.1 CMNOBP is called by:

A - CDERIV, OBD
B1 - CDERIV

7.3.2 CMNOBP calls:

DDOT, DMTML, NUTPRE, SERVCE

7.4 I/O Data

7.4.1 Inputs from COMMON

CKMER, CPOS, CRAD, D, DYN, E, EQ, PRENUT, PSI, RC, T, TSVT, TWOPI, XC, XO
IOBLAT, KLIBR, KSMNOB, KSOBL, MPLUSI, MPLUS3, ONE, TWO

7.4.2 Outputs to COMMON

PEROBL, PROPNL, XM

7.4.3 Other Inputs

K

4.4.4 Other Outputs

None

7.5 Symbols Used

7.5.1 COMMON Symbols

TPMAT, TPMAT1, TPMAT4, TPMAT5, TPMAT6

7.5.2 Other Symbols

7.5.2.1 Libration Matrix

AIOTA, CDEL, CEE, CI, CO, COSP, CV, DEL, DOSI, EE, G, GP, GW2, G2W2, OSP, SDEL, SEE, SG, SI, SIR, SO, SO2, SOSP, SOV, V, W, W2

AU, R

See Ref. 1, Appendix A

7.5.2.2 J_{20} Oblateness Term

PARC, PARU - temporary components.

ZDRSQ - $(Z/R)^2$

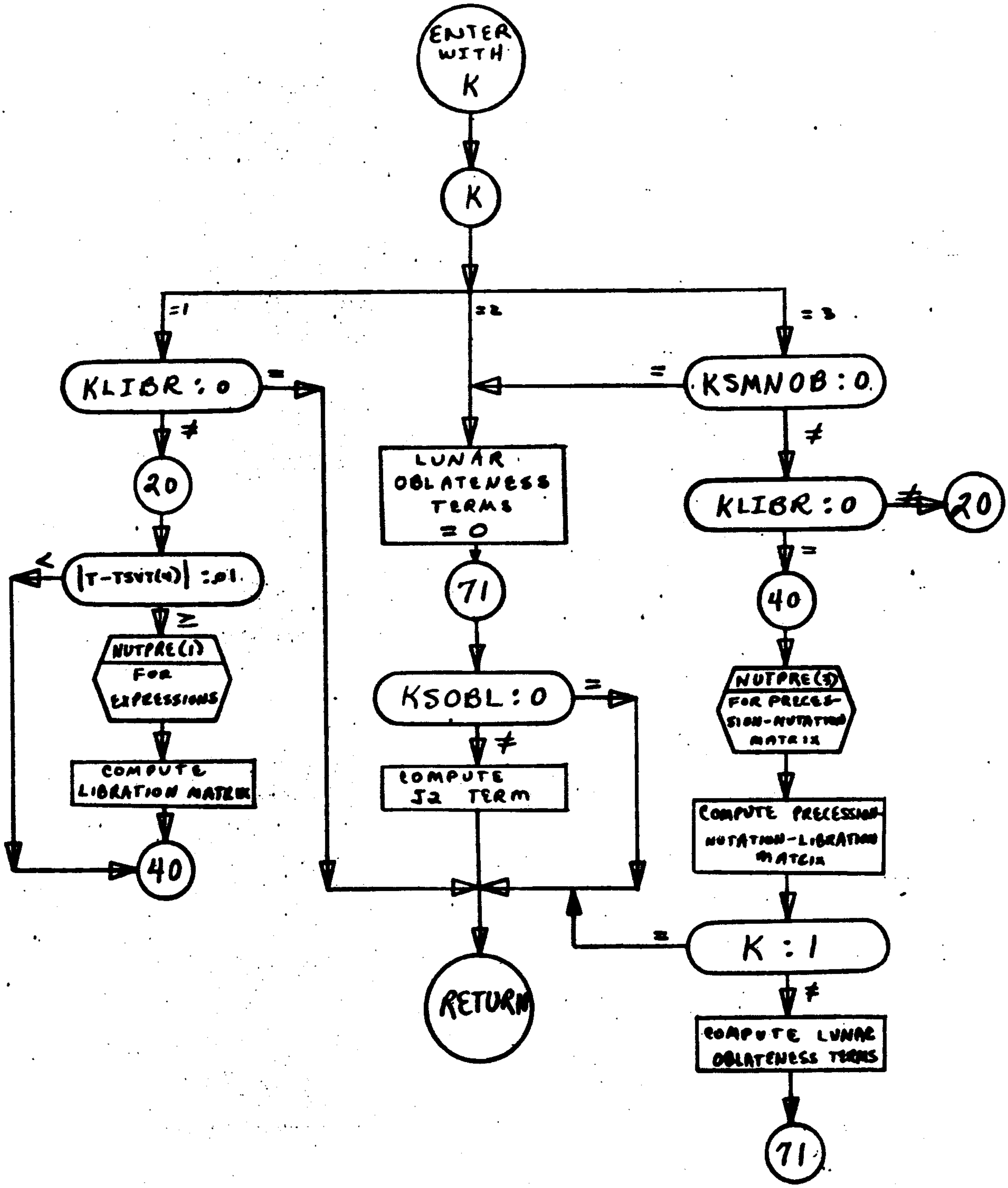
7.5.2.3 Lunar Oblateness Terms

REPR - temporary term.

7.6 Equations Used

See Ref. 1, Section 4 for Earth and Moon Oblateness

See Ref. 1, Appendix A for Libration.


ENTER WITH K
K
=1
=2
=3
KLIBR : 0
=
≠
20
|T-TSVT(4)| : .01
<
≥
NUTPRE(1) FOR EXPRESSIONS
COMPUTE LIBRATION MATRIX
40
KSMNOB : 0
LUNAR OBLATENESS TERMS = 0
71
KSOBL : 0
COMPUTE J2 TERM
RETURN
KLIBR : 0
20
40
NUTPRE(3) FOR PRECESSION-NUTATION MATRIX
COMPUTE PRECESSION-NUTATION-LIBRATION MATRIX
K : 1
COMPUTE LUNAR OBLATENESS TERMS
71

8. Subroutine CMVDRG

8.1 Purpose

This subroutine computes the perturbations due to drag in the Mars or Venus atmospheres in the Cowell integrator.

8.2 Method

The coefficient of drag is determined by interpolation from given drag tables as a function of relative vehicle velocity and altitude.

8.3 Program References

8.3.1 CMVDRG is called by:

CDERIV

8.3.2 CMVDRG calls:

SERVCE, DDOT

8.4 I/O Data

8.4.1 Inputs from COMMON

CKSERH, ERAD, RATEV, RC, RDC
CDT, DAREA, KSDRGM, KSDRGV, MPLUS1, MPLUS3, MWREF, RADII, VMASS, XMACH

8.4.2 Outputs to COMMON

DYN(50), PEROBL

8.4.3 Other Inputs

None

8.4.4 Other Outputs

None

8.5 Symbols Used

8.5.1 COMMON Symbols

TPMAT5

8.5.2 Other Symbols

AIT - height above planet surface

C - ratio of relative vehicle velocity to speed of sound at altitude

CD - drag coefficient

DRAG - temporary solution used in drag computation

PL - air density

VA(3) - components of relative velocity between vehicle and air mass at altitude

VAMAG - magnitude of VA(I)

XLOGPL - log of air density as interpolated from table, DEND

*AIDTD(15,I) - table of reference altitudes (Data)

*DEND(15,I) - table of densities at reference altitudes (Data)

*SPSD(15,I) - table of speed of sound at reference altitudes (Data)

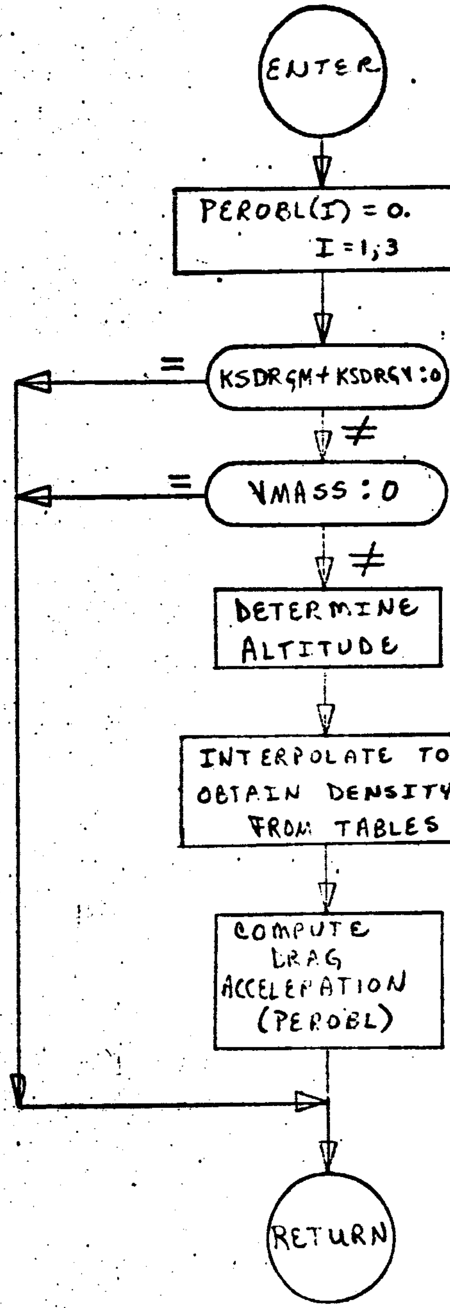
*I = 1 for Mars atmosphere

I = 2 for Venus atmosphere

8.6 Equations Used

See Reference 1, Section 4.

8.7 FLOW DIAGRAM - CMVDRG



9. Subroutine COBDRG

9.1 Purpose

This subroutine computes the oblateness and air drag perturbations due to earth for the Cowell integrator.

9.2 Method

Oblateness is computed in a flexible algorithm which can be used for zonal and tesseral harmonics of any order. The drag perturbation is computed in conjunction with Harris-Priester drag tables (high altitudes) or the U.S. Standard Atmosphere (low altitudes).

9.3 Program References

9.3.1 COBDRG is called by:

CDERIV

9.3.2 COBDRG calls:

CINTRP, DDOT, DMTML, DOMUD, NUTPRE, SERVCE

9.4 I/O Data

9.4.1 Inputs from COMMON

CKSERH, CRAD, DYN, EPSSQ, ERAD, GAM, HMU, PRENUT, RC, RDC
CDT, DAREA, IOBLAT, KOBLAT, KSDRG, KSOBL, M6, MPLUS1,
MPLUS2, MPLUS3, ONE, THREE, TWO, VMASS, XMACH

9.4.2 Outputs to COMMON

DYN, PEROBL
XLST

9.4.3 Other Inputs and Outputs

None

9.5 Symbols Used

9.5.1 COMMON Symbols

TPMAT, TPMAT4, TPMAT5

9.5.2 Other Symbols

9.5.2.1 Drag Portion

ALT - height above earth

CLAT - cosine of latitude of vehicle

DRAGE - density computed from tables

DRAGHI - temporary storage of DRAGE

GV - density from twilight tables and low altitude tables

VA (3) - components of velocity of vehicle with respect to air mass

VAMAG - magnitude of VA vector

XLQT - local solar time

ALTLO (32) - table of reference altitudes

DENLO (32) - table of reference air densities

SPSDLO (32) - table of reference speeds of sound

9.5.2.2 Oblateness Portion

ACOEFF, ATEMP, BCOEFF, BTEMP, COEFF, CTEMP, DG (3), DOEFF, GXY - temporary computed coefficients

HC (21) - factorials from 1 through 21

RTEMP (4) - components and magnitude of vehicle position vector transformed to geocentric system with X-axis through Greenwich

SAVE (3) - temporary storage for oblateness acceleration

VALUEB - temporary computed coefficient

X2, X2Y2, X33XY2, XYX2, Y33YX2, Y2, ZDR, ZDR2 - temporary values derived from X, Y, and Z

DR (3) - the 3 partials in eq. (30), Ref. 1, Sect. 4.3.2

ICMN - index of c coefficient desired (DYN array)

INDX - index

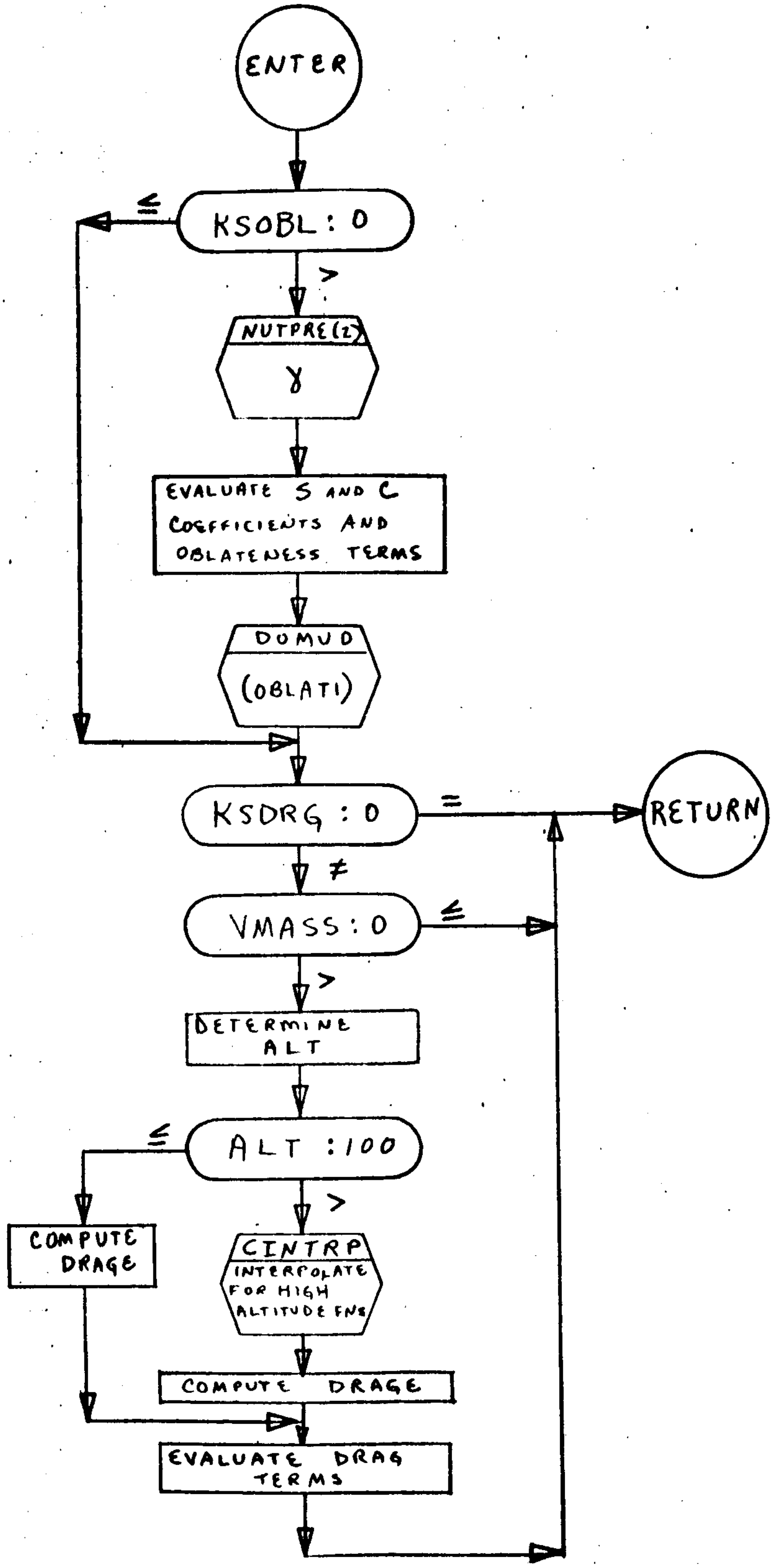
ISMN - index of S coefficient desired (DYN array)

LOBLAT, M, MP, N, NOFP, NM, XK, XM, XN, XNM, XNMK, XNMKM, XNOFP - temporary variables

9.6 Equations Used

See Ref. 1, Section 4.3.2 for Oblateness

See Ref. 1, Section 4.4 for Drag


ENTER
KSOBL : 0
≤
>
NUTPRE(2)
γ
EVALUATE S AND C COEFFICIENTS AND OBLATENESS TERMS
DOMUD
(OBLATI)
KSDRG : 0
=
RETURN
≠
VMASS : 0
≤
>
DETERMINE ALT
ALT : 100
≤
>
COMPUTE DRAGE
CINTRP
INTERPOLATE FOR HIGH ALTITUDE FNS
COMPUTE DRAGE
EVALUATE DRAG TERMS

10. Subroutine CRSTRE (ICR)

10.1 Purpose

This subroutine saves or restores time, position, velocity and acceleration of the vehicle at any d[illegible] time - for the Cowell integra[illegible].

10.2 Method

When ICR ≤ 1 the inform[illegible] is saved

When ICR > 1 the saved information is restored

10.3 Program References

CRSTRE is called by:

A - ATIM, CITGRA, MAINA
B1 - CITGRA

10.4 I/O Data

10.4.1 Inputs from COMMON

RC, RCINT, RDC, RDCINT, RDDOT, RDDOTS, T, TINT
IP, IPINT

10.4.2 Outputs to COMMON

RC, RCINT, RDC, RDCINT, RDDOT, RDDOTS, T, TINT
IP, IPINT

10.4.3 Other Inputs

ICR

10.4.4 Other Ouputs

None

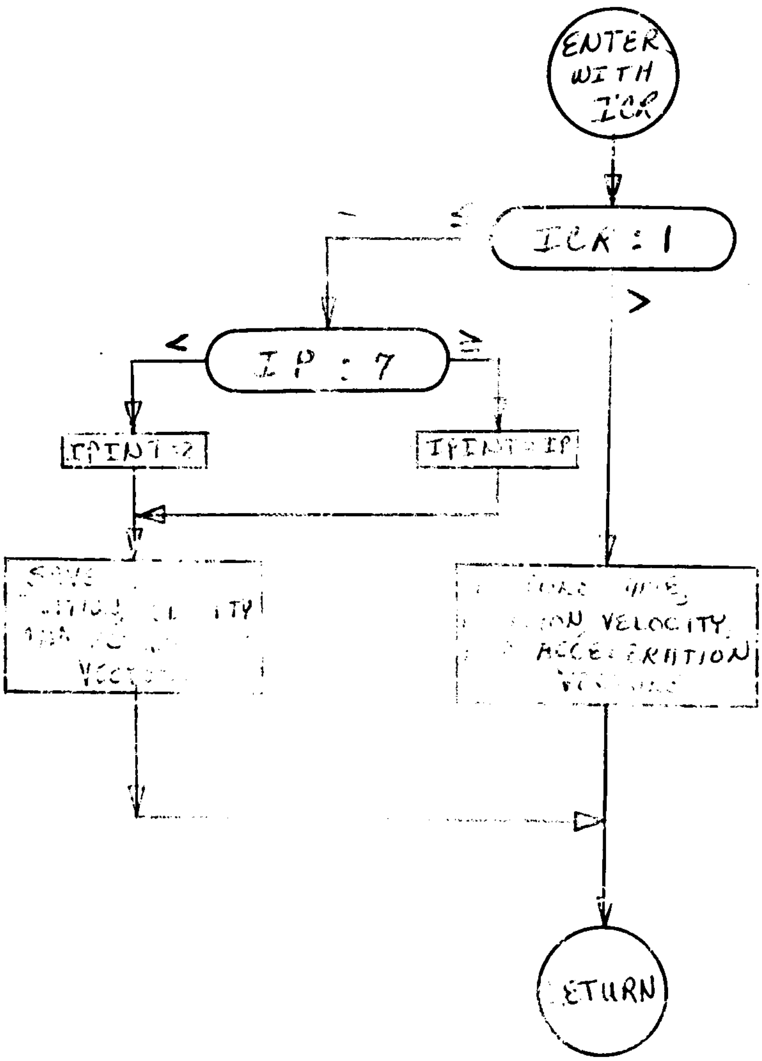
10.5 Symbols Used other than COMMON

None

10.6 Equations Used

None

10.7 FLOW DIAGRAM - CRSTRE



11. Function DDOT (A,B)

11.1 Purpose

This function computes the dot product of 2 vectors.

11.2 Method

Components of the vectors are in the calling sequence.

11.3 Program References

DDOT is called by most routines in A, B1, and B2 programs.

11.4 I/O Data

11.4.1 Inputs

A - the first input vector
B - the second input vector

11.4.2 Outputs

the DDOT

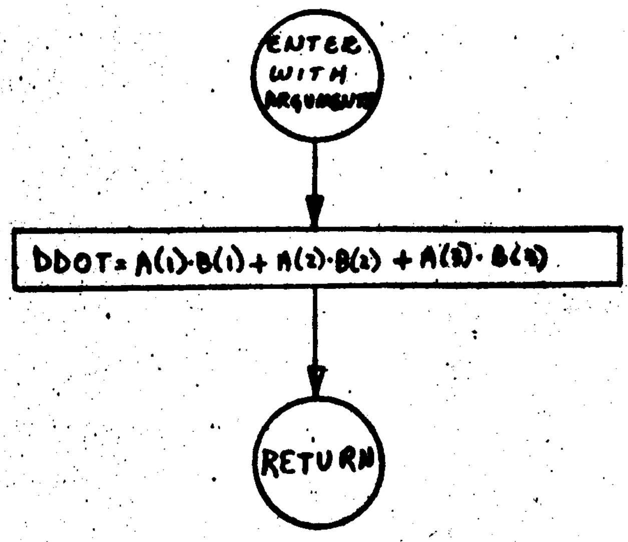
11.5 Symbols Used

None

11.6 Equations Used

$$DDOT = A_1 B_1 + A_2 B_2 + A_3 B_3$$

11.7 FLOW DIAGRAM - DDOT



12. Subroutine DMTML (A,B,C,I,J,K,L,M,N,IAC,JAB,KBC,IFLAG)

12.1 Purpose

This subroutine multiplies two double-precision matrices of any size up to 26 x 26 normally, or two matrices in which the second is transposed. The result is stored either in a third matrix or in one of the two input matrices.

12.2 Method

When IFLAG = 0,1 multiplication is done by rows of A so that A can be overwritten if desired.

When IFLAG = 2, B is transposed and then proceeds as for IFLAG = 3.

Note: Care must be taken that the product AB^T will fit with the dimensions of B.

When IFLAG = 3, multiplication is done by columns of B and the result is stored in B.

12.3 Program References

DMTML is called by many subroutines in A, B1 and B2.

12.4 I/O Data

12.4.1 Inputs

A - the first input matrix

B - the second input matrix

I - number of rows A is actually dimensioned by

J - number of columns A is actually dimensioned by

K - number of rows B is actually dimensioned by

L - number of columns B is actually dimensioned by

M - number of rows C is actually dimensioned by

N - number of columns C is actually dimensioned by

IAC – number of rows of A and C to be used

JAB – number of columns of A and rows of B (or B^T) to be used

KBC – number of columns of B (or B^T) and C to be used

IFLAG – flag for type of multiplication and where stored

= 0 A . B in C (or A)

= 1 A . B in C (or A)

= 2 A . B^T in B

= 3 A . B in B

12.4.2 Outputs

C – resultant matrix – either A, B or a third C

12.5 Symbols Used

SAVRO(26) – the saved row of A or column of B

X – temporary storage

IFLG1 – flag word

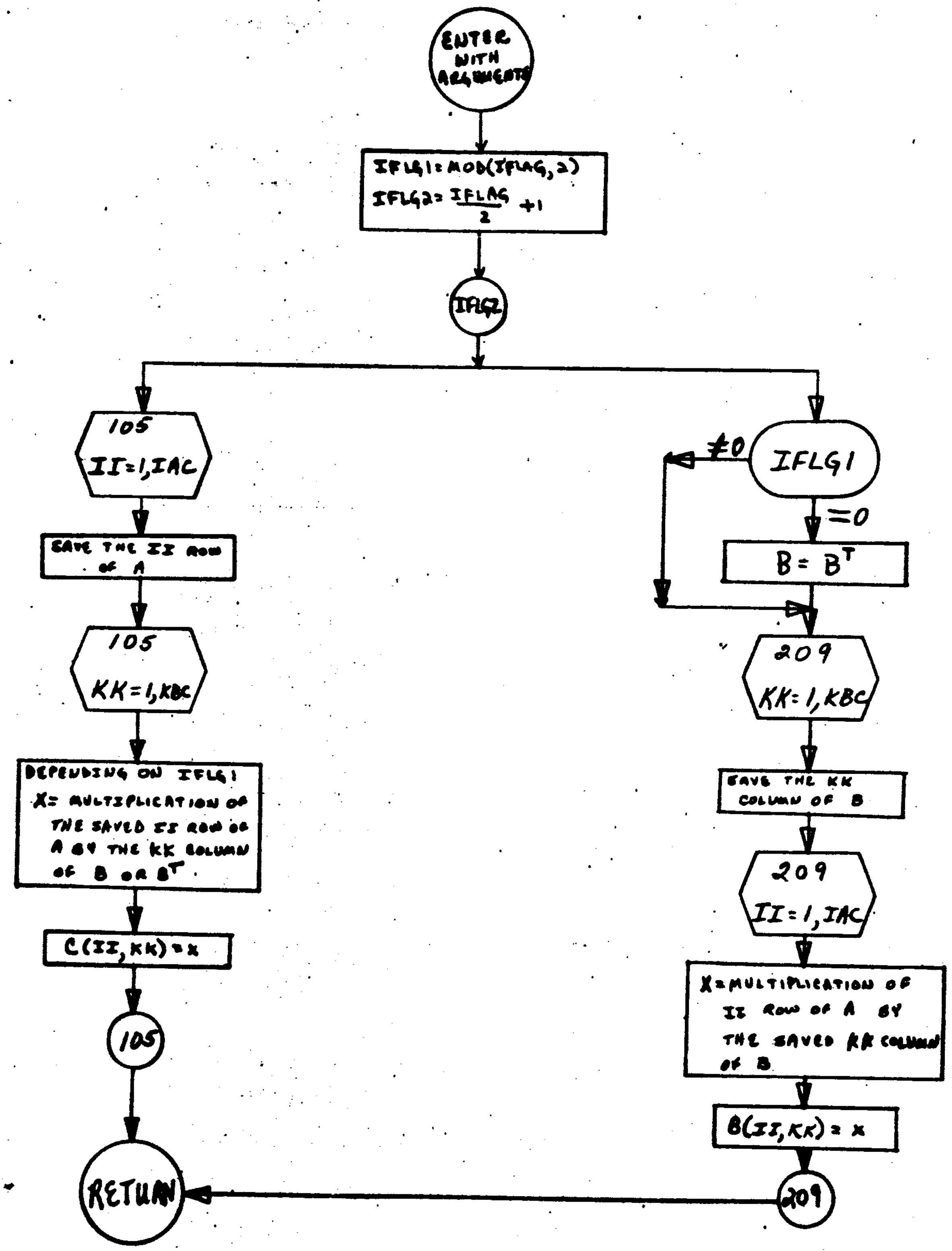
IFLG2 – flag word

12.6 Equations Used

$$C(I,J) = \sum A(I,K) \cdot B(K,J) \qquad \text{for } A \cdot B$$

$$C(I,J) = \sum A(I,K) \cdot B(J,K) \qquad \text{for } A \cdot B^T$$

12.7 FLOW DIAGRAM - DMTML



13. Subroutine DOMUD (TEST)

13.1 Purpose

This subroutine decides whether an error has occurred.

13.2 Method

The program checks the Overflow and Divide check indicators. If either is on, AMUD is set equal to TEST and an error printout is written, unless TEST = 0.

13.3 Program References

13.3.1 DOMUD is called by:

A - CDERIV, COBDRG, EDERIV, EOBDRG, KEPLER, NUTPRE, OBSERA, PRINTA, RECT, STAPOS, XFORM

B1 - DALFA, INPTB1, PASMB1, PTB1, STATB1

13.3.2 DOMUD calls:

DVCHK, OVERFL

13.4 I/O Data

13.4.1 Inputs from COMMON

None

13.4.2 Outputs to COMMON

AMUD

13.4.3 Other Inputs

TEST

13.4.4 Other Outputs

"Error in (TEST)" - when either indication is on

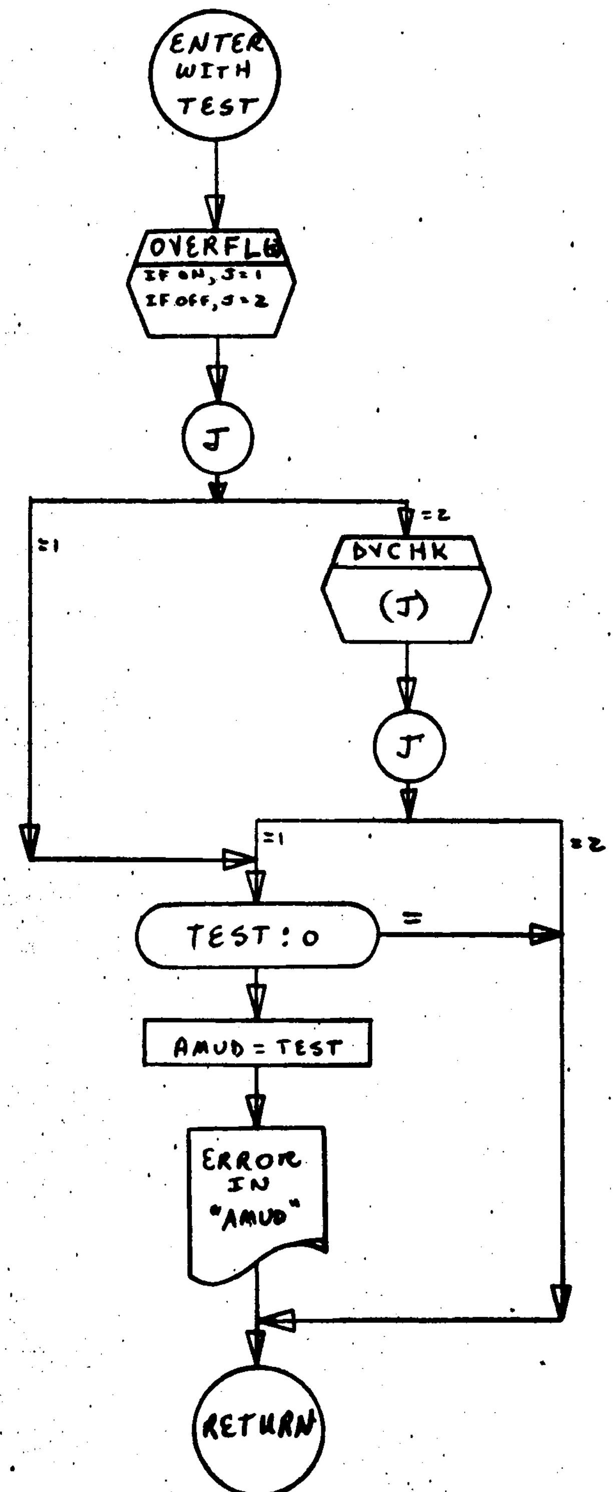
13.5 Symbols Used Other Than COMMON

J - flag for divide check and overflow indicators = 1, on = 2, off

13.6 Equations Used

None

13.7 FLOW DIAGRAM - DOMUD



14. Subroutine ECHREF

14.1 Purpose

This subroutine determines when to change the reference body, for Encke integration.

14.2 Method

See CCHREF (2.)

14.3 Program References

14.3.1 ECHREF is called by:

EITGRA

14.3.2 ECHREF calls:

DDOT, EPHEM, KEPLER, SERVCE

14.4 I/O Data

14.4.1 Inputs from COMMON

CPOS, CVEL, DPADD(1-3), DPADD(10), DT3, RC, RDTB, RTB, T
KS2BY, KWBMU, MBMAX, MPLUS1, MPLUS2, MPLUS3, MWREF, ONE

14.4.2 Outputs to COMMON

DPADD(1-7), DT3, RC, RDC, T
KOMP, MWREF

14.5 Symbols Used

14.5.1 COMMON Symbols

TPMAT4, TPMAT5, TPMAT6, TPMAT7, TPMAT8

14.5.2 Other Symbols

RACT(7) - radius of activity for each of 7 bodies

RMAGF - open function to compute magnitude of a vector

INDX - index denoting reference body

ISW - index used in earth-moon reference

MRFS - saved MWREF

SWT - switch used in earth-moon reference

14.6 Equations Used

See Ref. 1, Section 3.5.

14.7 Flow Diagram

See CCHREF (2.7)

15. Subroutine EDERIV

15.1 Purpose

This subroutine evaluates the perturbation terms for the Encke integrator. There are two versions of this routine. The maximum version includes radiation pressure acceleration terms and eclipse information. In the minimum version, these computations are eliminated.

15.2 Method

This subroutine computes the Encke terms, the planetary perturbations, and the radiation pressure perturbations. The effect of thrust is included by assuming that the powered flight trajectory can be computed from a Chebyshev polynomial expansion based on the initial thrust conditions, vehicle mass and mass rate. Earth oblateness and drag are computed in the subsidiary subroutine EOBDRG, lunar oblateness perturbations in EMNOBP, and the drag of Mars and Venus atmosphere in EMVDRG.

15.3 Program References

15.3.1 EDERIV is called by:

EINT

15.3.2 EDERIV calls:

DDOT, DOMUD, EMNOBP, EMVDRG, EOBDRG, EPHEM, KEPLER, PFIGHT, SERVCE

15.4 I/O Data

15.4.1 Inputs from COMMON
15.4.1.1

CPOS, DYN, PEROBL, RDTB, RTB
CWLIN, KSDRG, KSPLT, KWBMU, MBMAX, MPLUS1, MPLUS2, MPLUS3, MWREF,
PFON, THREE, TWO

15.4.1.2 Radiation Pressure portion only

DPADD(11-15), DYN, T, TWOPI
IXADD(1-4), KECLPS, KSRAP, MPLUS1, ONE, RADII

15.4.2 Outputs to COMMON

15.4.2.1 RC, RDC

15.4.2 Radiation Pressure portion only

DPADD(11-15), DYN
IXADD(1-4)

15.5 <u>Symbols Used</u>

15.5.1 COMMON Symbols-used only in Radiation Pressure portion

TPMAT2, TPMAT4, TPMAT5, TPMAT6, TPMAT7, TPMAT8, TPMAT9

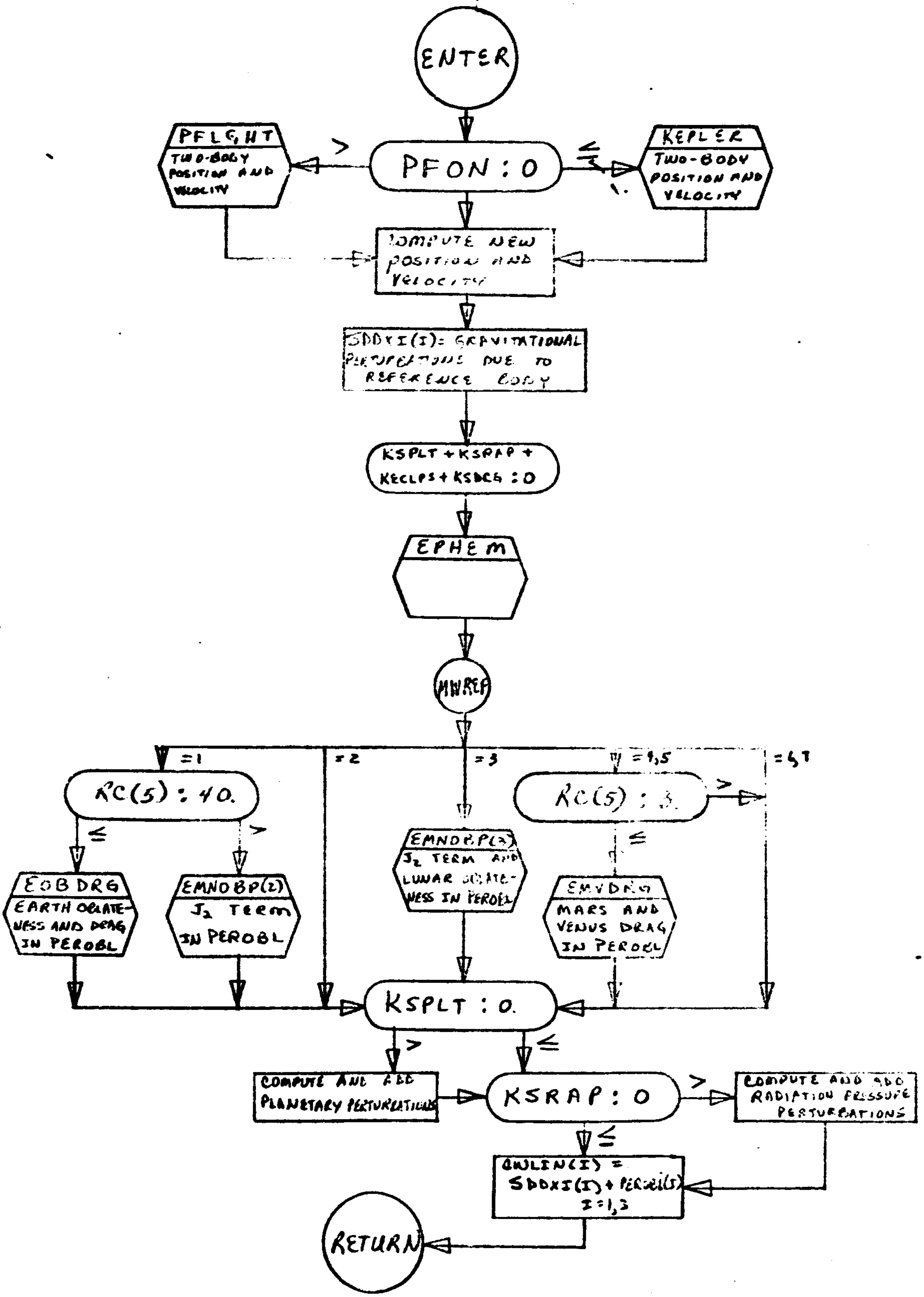
15.5.2 Other Symbols

See CDERIV(3.5.2) with the exception that DU and SLDXI are single precision variables.

15.6 <u>Equations Used</u>

See Ref. 1, Section 4.

15.7 FLOW DIAGRAM - EDERIV



16. Subroutine EINT (IENT)

16.1 Purpose

The subroutine is the Encke integrator. Runge-Kutta integration is used for short time integration and to start the Nordsieck long time integration.

16.2 Method

Single precision solution of accelerations are used throughout. Rectification occurs at frequent intervals so that roundoff in the single precision integrator does not unduly affect the precision of the Encke Method.

16.3 Program References

16.3.1 EINT is called by:

ATIM, EITGRA

16.3.2 EINT calls:

EDERIV

16.4 I/O Data

16.4.1 Inputs from COMMON

See CINT plus CWLIN (4.)

16.4.2 Outputs to COMMON

See CINT

16.4.3 Other Inputs

IENT

16.4.4 Other outputs

None

16.5 <u>Symbols Used</u>

See CINT

16.6 <u>Equations Used</u>

See CINT

16.7 <u>Flow Diagram</u>

See CINT (4.7)

17. Subroutine EINTRP (X1, X2, X3, GV, DRAGHI)

This subroutine is essentially the same as subroutine CINTRP (5.).

The differences, which arise from the fact that it is used in a different program link, are:

a) EINTRP is called by

EOBDRG

b) the variables AL, H, GV, X1, X2, X3 are single precision.

18. Subroutine EITGRA

18.1 Purpose

This subroutine serves as the sub-main program governing calls to the integration subroutines in the Encke method.

18.2 Method

See CITGRA (6.)

18.3 Program References

18.3.1 EITGRA is called by:

A - MAINA
B1 - MAIN B1

18.3.2 EITGRA calls:

ECHREF, EINT, ERSTRE, KEPLER, RECT

18.4 I/O Data

18.4.1 Inputs from COMMON

DT, DT3, OLDT, PFPAR, PRNT3, R1, R2, RC, RDTB, RT1, RT2, RTB, T, TD, ECOM
CNT, CWLIN, FPK, IDER, IP, IPFT, IXADD(14), IXADD(16), KOMP, KS2BY,
KSPLT, LML, MAXSTA, MPLUS1, MPLUS2, MPLUS3, MWREF, ONE, PFON, PURP, RTO,
SPADD(9), THREE

18.4.2 Outputs to COMMON

DELTP, DTI, OLDT, RC, RDC, SAVD, T, TD
CNT, IDER, IP, KOMP, NSTA, SPADD(9), TSTRO

18.4.3 Other Inputs

None

18.4.4 Other Outputs

None

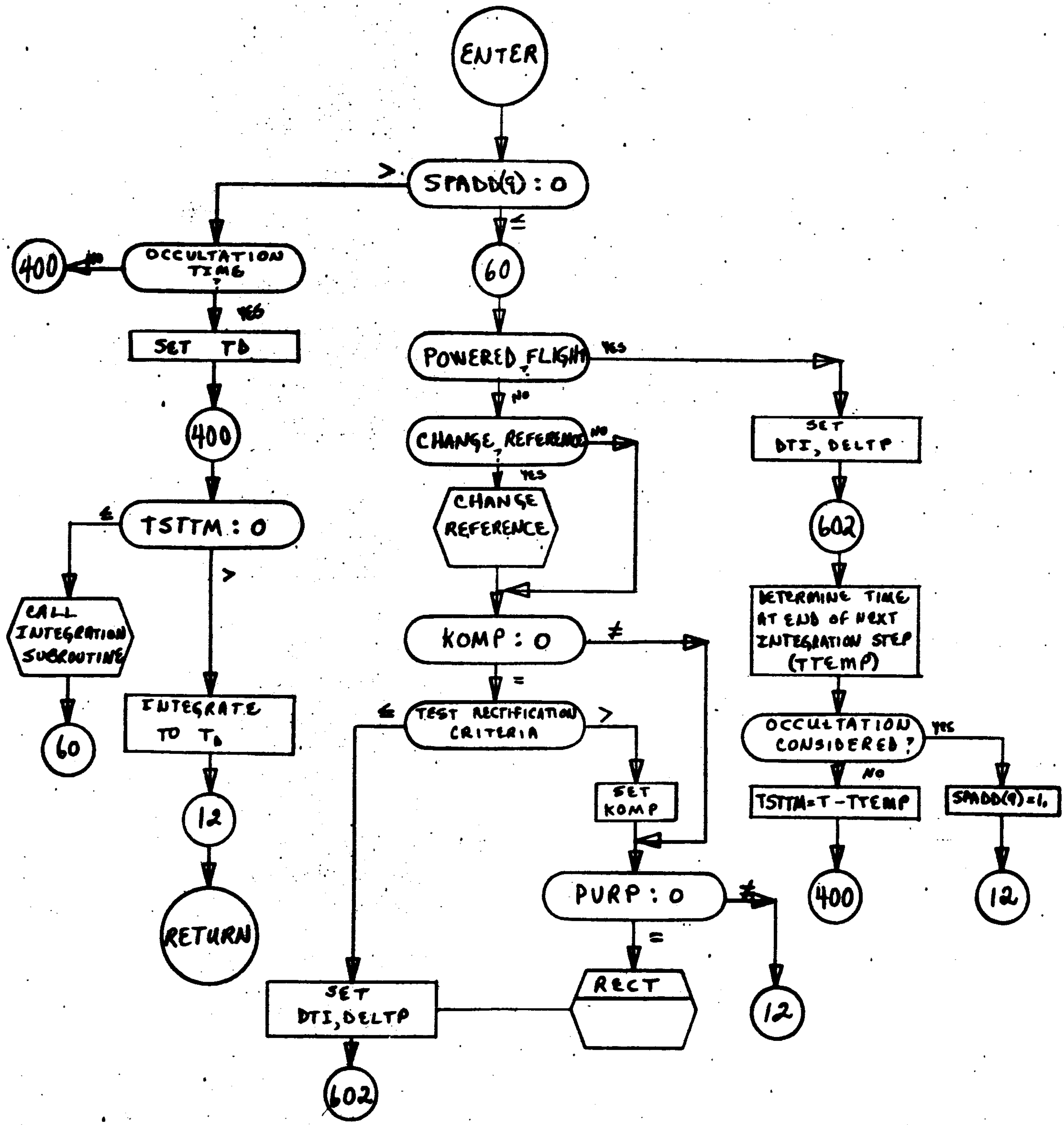
18.5 Symbols Used

See CITGRA

18.6 Equations Used

None

18.7 FLOW DIAGRAM - EITGRA



19. Subroutine EMNOBP (K)

This subroutine is an exact duplicate of subroutine CMNOBP (7.). Its usage differs in that it is called by EDERIV rather than CDERIV.

20. Subroutine EMVDRG

20.1 Purpose

This subroutine computes the drag accelerations due to the atmospheres of Mars and Venus in the Encke integrator.

20.2 Method

The coefficient of drag is determined by interpolation from given drag tables as a function of relative vehicle velocity and altitude.

20.3 Program References

20.3.1 EMVDRG is called by:

EDERIV

20.3.2 EMVDRG calls:

DDOT, SERVCE

20.4 Input/Output Data

See CMVDRG (8)

20.5 Symbols Used

See CMVDRG

20.6 Equations Used

See Reference 1, Section 4.

20.7 Flow Diagram

See CMVDRG (8.7)

21. Subroutine EOBDRG

21.1 Purpose

This subroutine computes the oblateness and air drag perturbations due to earth for the Encke integrator.

21.2 Method

See COBDRG (9)

21.3 Program References

21.3.1 EOBDRG is called by:

EDERIV

21.3.2 EOBDRG calls:

EINTRP, DDOT, DMTML, DOMUD, NUTPRE, SERVCE

21.4 I/O Data

See COBDRG

21.5 Symbols Used

See COBDRG with the following exceptions:

a) XLQT is omitted

b) Most of the variables used are single precision.

21.6 Equations Used

See Ref. 1, Section 4.3.2 for Oblateness

See Ref. 2, Section 4.4 for Drag

21.7 Flow Diagram

See COBDRG

22. Subroutine EPHEM

22.1 Purpose

This subroutine evaluates the position and velocity vectors of each of the 7 bodies with respect to the reference body.

22.2 Method

Tabular planetary positions are read from an ephemeris tape and interpolated to give values for current time. An Everett's Interpolation Formula for equal tabular intervals is used.

22.3 Program References

22.3.1 EPHEM is called by:

CCHREF, CDERIV, ECHREF, EDERIV, STACUL

22.3.2 EPHEM calls:

SERVCE

22.4 I/O Data

22.4.1 Inputs from COMMON

AUERAD, DPADD (16), DPADD (17)
IXADD (19), MPLUS2, MWREF, ONE, THREE, TWO

22.4.2 Outputs to COMMON

CPOS, CVEL, DPADD (16), DPADD (17)
IXADD (19)

22.4.3 Other Inputs - from logical tape 8

WASTE, TABLE (210)

22.4.4 Other Outputs

None

22.5 Symbols Used

22.5.1 COMMON Symbols

TPMAT4, TPMAT5, TPMAT6, TPMAT7, TPMT11

22.5.2 Other Symbols

HOUR - current time, from beginning of launch year

AEPH (6) - (Data) - array of intervals, in hours, for six planetary ephemerides.

I2 - Index used in interpolation

IEPH (7) - (Data) - array indicating correspondence between sequence of planets on tape and in CPOS array.

IR - Index used in properly positioning ephemeris tape.

JEPH (6) - Array generated for use in choosing correct tabular values.

K - index used in interpolation

K2 - index used in interpolation

KEPM (6) - (Data) - Array indicating number of tabular values for each coordinate of the six planetary bodies.

TEST - Value usedto determine if ephemeris tape must be read at current time.

22.6 Equations Used

Given tabular values f_{-2}, f_{-1}, f_0, f_1, f_2, and f_3 corresponding to times T_{-2}, T_{-1}, T_0, T_1, T_2 and T_3. It is desired to find f (T) for $T_0 < T < T_1$. Everett's formula yields:

$$f(T) = f_0 + \delta_{\frac{1}{2}} n + \delta_0^2 E_0^2 + \delta_1^2 E_1^2 + \delta_0^4 E_0^4 + \delta_1^4 E_1^4$$

where, $n = (T - T_0)/(T_1 - T_0)$

$$\delta_{\frac{1}{2}} = f_1 - f_0$$

$$\delta_0^2 = f_1 - 2f_0 + f_{-1}$$

$$\delta_1^2 = f_2 - 2f_1 + f_0$$

$$\delta_0^4 = f_2 - 4f_1 + 6f_0 - 4f_{-1} + f_{-2}$$

$$E_0^2 = -n(n-1)(n-2)/6$$

$$E_1^2 = (n+1)n(n-1)/6$$

$$E_0^4 = -(n+1)n(n-1)(n-2)(n-3)/120$$

$$E_1^4 = (n+2)(n+1)n(n-1)(n-2)/120$$

The velocity is given by:

$$\dot{f}(T) = \left\{ \delta_{\frac{1}{2}} + \delta_0^2 \frac{dE_0^2}{dn} + \delta_1^2 \frac{dE_1^2}{dn} + \delta_0^4 \frac{dE_0^4}{dn} + \delta_1 \frac{dE_1^4}{dn} \right\} \frac{dn}{dT}$$

where,

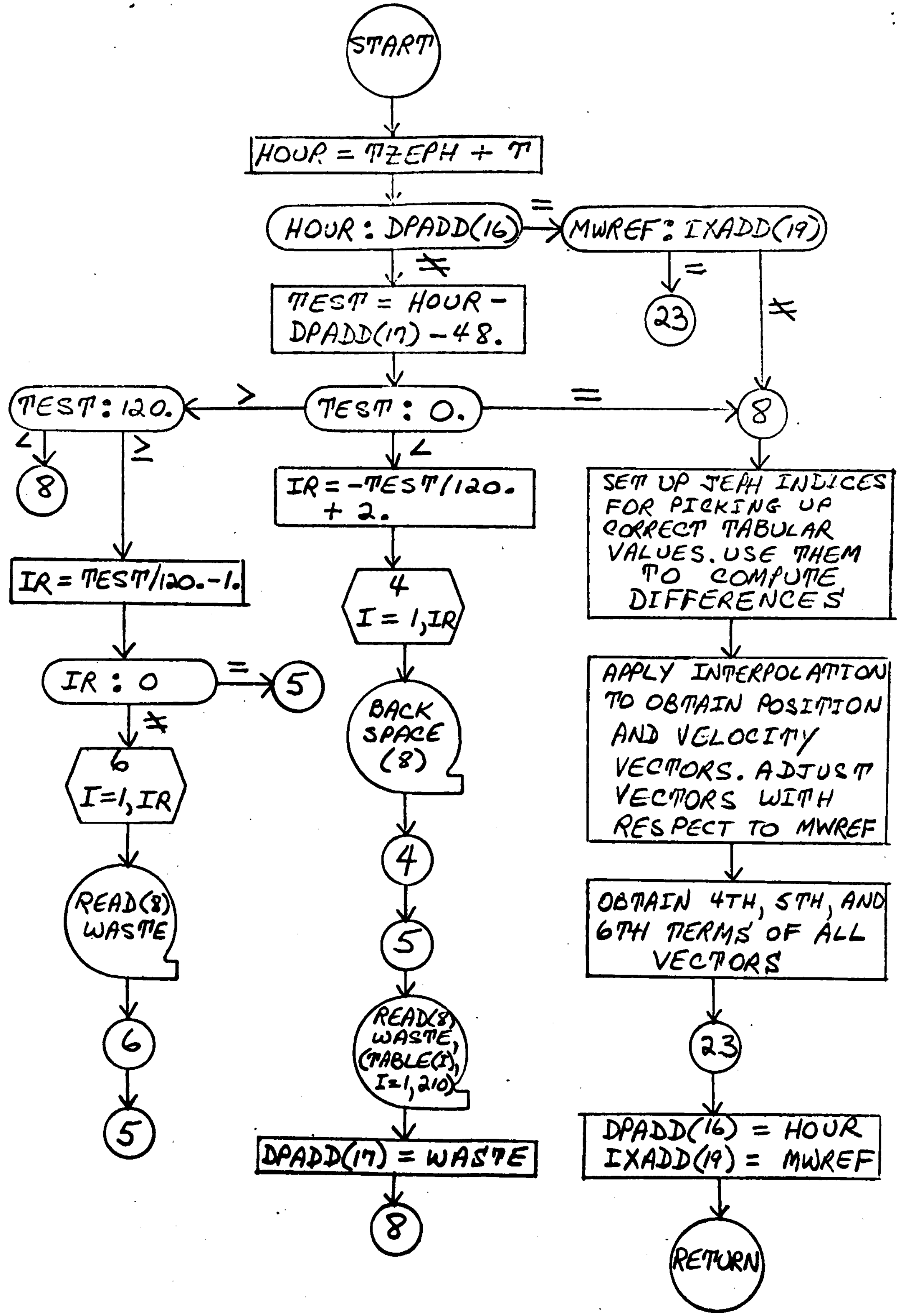
$$\frac{dn}{dT} = \frac{1}{T_1 - T_0}$$

$$\frac{dE_0^2}{dn} = -(3n^2 - 6n + 2)/6$$

$$\frac{dE_1^2}{dn} = (3n^2 - 1)/6$$

$$\frac{dE_0^4}{dn} = -(5n^4 - 20n^3 + 15n^2 + 10n - 6)/120$$

$$\frac{dE_1^4}{dn} = (5n^4 - 15n^2 + 4)/120$$


START
HOUR = TZEPH + T
HOUR : DPADD(16)
=
≠
MWREF : IXADD(19)
=
23
≠
TEST = HOUR - DPADD(17) - 48.
TEST : 0.
>
=
8
<
TEST : 120.
<
8
≥
IR = TEST/120.-1.
IR : 0
=
5
≠
6 I=1, IR
READ(8) WASTE
6
5
IR = -TEST/120. + 2.
4 I = 1, IR
BACK SPACE (8)
4
5
READ(8) WASTE, (TABLE(I), I=1, 210)
DPADD(17) = WASTE
8
SET UP JEPH INDICES FOR PICKING UP CORRECT TABULAR VALUES. USE THEM TO COMPUTE DIFFERENCES
APPLY INTERPOLATION TO OBTAIN POSITION AND VELOCITY VECTORS. ADJUST VECTORS WITH RESPECT TO MWREF
OBTAIN 4TH, 5TH, AND 6TH TERMS OF ALL VECTORS
23
DPADD(16) = HOUR
IXADD(19) = MWREF
RETURN

23. Subroutine ERSTRE (IER)

23.1 Purpose

This subroutine saves or restores time, position, velocity and the perturbations of the vehicle at any designated time - for the Encke integrator.

23.2 Method

When IER $\leq$ 1 the information is saved
When IER $>$ 1 the saved information is restored

23.3 Program References

ERSTRE is called by:

A - ATIM, EITGRA, MAINA
B1 - EITGRA

23.4 I/O Data

23.4.1 Inputs from COMMON

RC, RCINT, RDC, RDCINT, T, TINT
CWLIN, CWLINT, IP, IPINT

23.4.2 Outputs to COMMON

Same as Input.

23.4.3 Other Inputs

IER

23.4.4 Other Outputs

None

23.5 Symbols Used

None

23.6 Equations Used

None

23.7 Flow Diagram

See CRSTRE (10.7) using IER rather than ICR.

24. EXECA

24.1 Purpose

This is the executive routine for the A mode.

24.2 Method

The program simply alternates between calling INPUTA and MAINA until all cases have been exhausted.

24.3 Program References

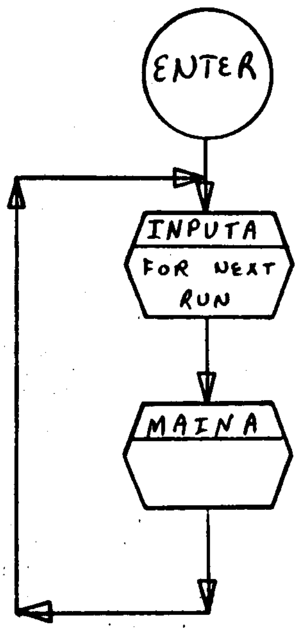
EXECA calls:

INPUTA, MAINA

24.4 Symbols

No COMMON or internal variables used.

24.5 FLOW DIAGRAM - EXECA



25. Subroutine FIX (KTEMP, ITEMP, KNAME)

25.1 Purpose

This subroutine unpacks a word into 5 separate words.

25.2 Method

See "Equations Used" section.

25.3 Program References

FIX is called by many subroutines in A, B1 and B2 programs.

25.4 I/O Data

25.4.1 Inputs

KTEMP - the packed word

25.4.2 Outputs

ITEMP(4) - the 4 low order portions of KTEMP

KNAME - the high order portion of KTEMP

25.5 Symbols Used

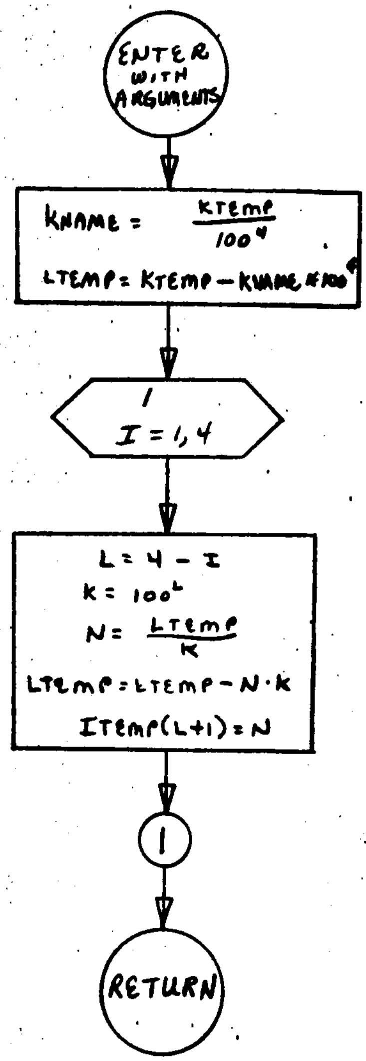
$$\left.\begin{array}{l}\text{ITEMP} -\\ \text{L} -\\ \text{K} -\\ \text{N} -\end{array}\right\}\ \text{temporary locations}$$

25.6 Equations Used

$$KNAME = KTEMP/100^4$$

$$ITEMP(1) + ITEMP(2) * 100 + ITEMP(3) * 100^2 + ITEMP(4) * 100^3$$

25.7 FLOW DIAGRAM - FIX



26. Subroutine INPUTA

26.1 Purpose

This subroutine reads in all data necessary for one run.

26.2 Method

The subroutine initializes necessary data and reads in sections desired. Depending on the input quantity KSTDRD, certain variables are either read in or set up within the program to nominal values.

26.3 Program References

26.3.1 INPUTA is called by:

EXECA

26.3.2 INPUTA calls:

XFORM

26.4 I/O Data

26.4.1 Inputs from COMMON

None

26.4.2 Outputs to COMMON

INPERR

plus all initialized and inputted data

26.4.3 Other Inputs

For a complete listing of data deck, see Ref. 2, Section 2.1

26.4.4 Other Outputs

A printout is made of all input quantities

26.5 Symbols Used

26.5.1 COMMON Symbols

TPMAT4, TPMAT8, TPMAT9

26.5.2 Other Symbols

DYNARR(60) - (Data) - nominal values of dynamic states

SCAL(3,7) - (Data) - the matrix from which the array SCALE is chosen, depending on IUNIT

TZ - time from start of launch day

ALPHA(3,7) - (Data) - matrix from which the array PVALPH is chosen, depending on IUNIT

CDN(40) - (Data) - standard coefficient of drag table from which which CDT is set up

DAYN - number of days from January 1, 1960 to start of launch year

ICMN - index for correct coefficient C_{mn} in the DYN array

IPR(2) - (Data) - BCD information of integration methods

IR - index to tell how many records to skip to bring Ephemeris tape up to current time

IR2 - the BCD word indicating the specified integration method

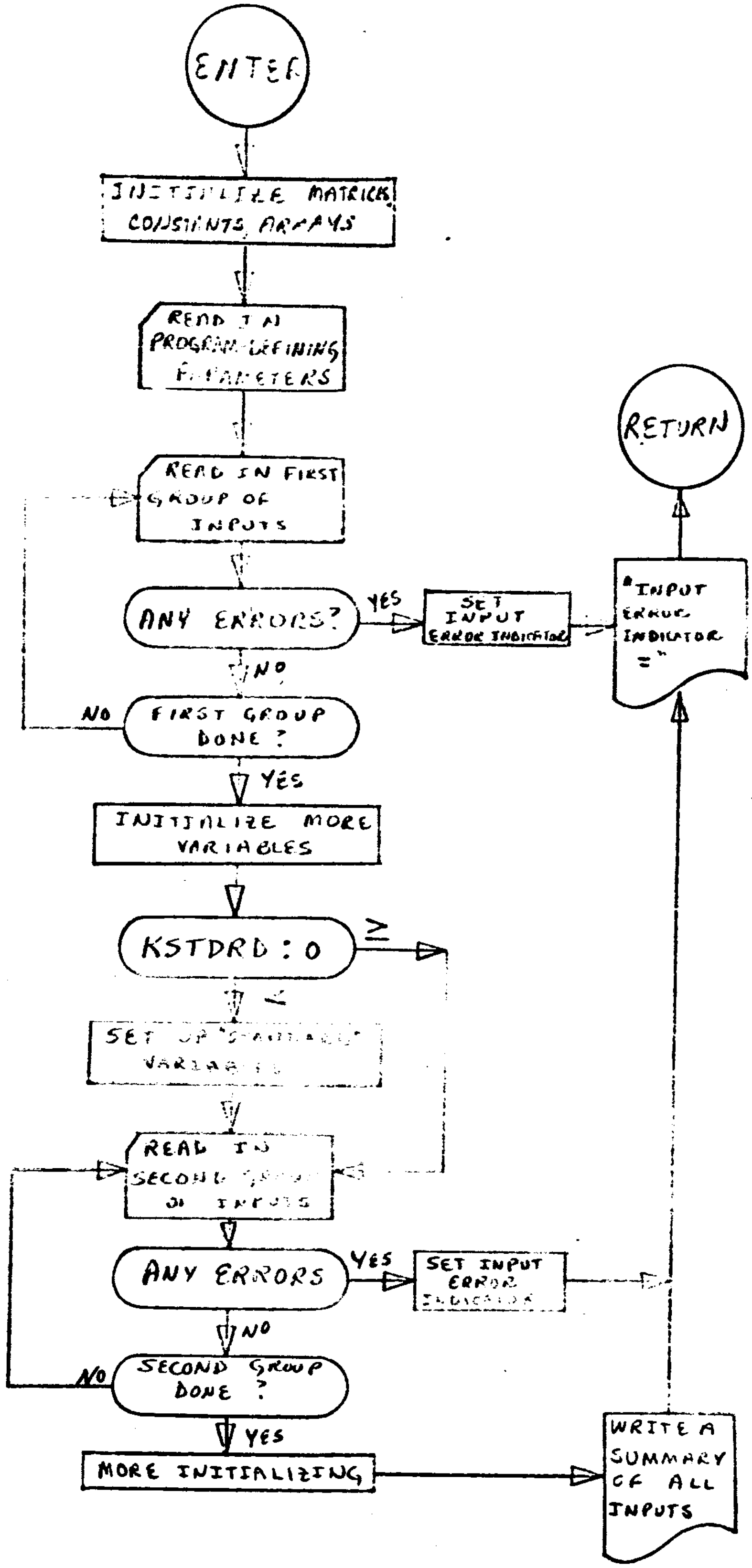
ISMN - index for correct S_{mn} in the DYN array

ITITLE(12) - array read in for title of run

XMACHN(40) - (Data) - standard Mach number tables from which XMACH is set up

26.6 Equations Used

None


ENTER
INITIALIZE MATRICES CONSTANTS ARRAYS
READ IN PROGRAM DEFINING PARAMETERS
READ IN FIRST GROUP OF INPUTS
ANY ERRORS?
YES
SET INPUT ERROR INDICATOR
NO
FIRST GROUP DONE ?
NO
YES
INITIALIZE MORE VARIABLES
KSTDRD : 0
≥
<
SET UP "STANDARD" VARIABLES
READ IN SECOND GROUP OF INPUTS
ANY ERRORS
YES
SET INPUT ERROR INDICATOR
NO
SECOND GROUP DONE ?
NO
YES
MORE INITIALIZING
WRITE A SUMMARY OF ALL INPUTS
"INPUT ERROR INDICATOR ="
RETURN

27. Subroutine KEPLER

27.1 Purpose

This subroutine computes the two-body position and velocity vectors.

27.2 Method

A Newton Rapheson scheme is used to determine the differential eccentric anomaly (BETA). After convergence, the two-body position and velocity vectors are evaluated.

27.3 Program References

27.3.1 KEPLER is called by:

ATIM, ECHREF, EDERIV, EITGRA, OBSERA, STACUL

27.3.2 KEPLER calls:

DOMUD, SERVCE

27.4 I/O Data

27.4.1 Inputs from COMMON

CZ, DZ, RA, RDI, RI, SQTMU, T, TH, TI, TKEP
MPLUS1, MPLUS2, MPLUS3, ONE

27.4.2 Outputs to COMMON

BETA, EF1, EF2, EF6, EF7, RDTB, RTB, TBF, TBFD, TBG, TBGD, TH, TKEP, XFAC
KOMP

27.4.3 Other Inputs and Outputs

None

27.5 Symbols Used

27.5.1 COMMON Symbols

TPMAT4, TPMAT5

27.5.2 Other Symbols

C = See Equation (5)

$DB = - r_o - d_o S - c_o C$

$DELTM = \sqrt{\mu} \; (t-t_I)$

DIFF = error term in Newton-Rapheson iteration

R = equation (9)

SC = equation (8)

U = equation (4)

X - saved value of TH

CFCN(14,2) - (Data) coefficients used in developing the Kepler series

KEP - counter on iterations in Newton-Rapheson method

KEP1 - BCD word = KEPH

27.6 Equations Used

$$n = \sqrt{\mu} \tag{1}$$

where

μ = gravitational constant of the reference body

$$M = n(t-t_I) \tag{2}$$

where t = current time

t_I = time of last rectification

X is computed by solution of the transcendental equation:

$$M = r_o X + d_o C + c_o U = n(t - t_I) \tag{3}$$

where

r_o = magnitude of position vector at last rectification

c_o, d_o = initial values for series expansions and

$$U = X^3 \sum \frac{1}{3!} - \frac{X^2}{5!a} + \frac{X^4}{7!a^2} - \frac{X^6}{9!a^3} + \cdots \tag{4}$$

$$C = X^2 \sum \frac{1}{2!} - \frac{X^2}{4!a} + \frac{X^4}{6!a^2} - \frac{X^6}{8!a^3} + \cdots \tag{5}$$

where

a = semimajor axis of two-body orbit.

After solving for an X that satisfies equations (3) through (5), $R(t)$ and $\dot{R}(t)$ are found using the following equations:

$$f = 1 - \frac{C}{r_o} \tag{6}$$

$$g = \frac{M - U}{\sqrt{\mu}} \tag{7}$$

$$S = X - \frac{U}{a} \tag{8}$$

$$r = r_o - d_o S + c_o C \tag{9}$$

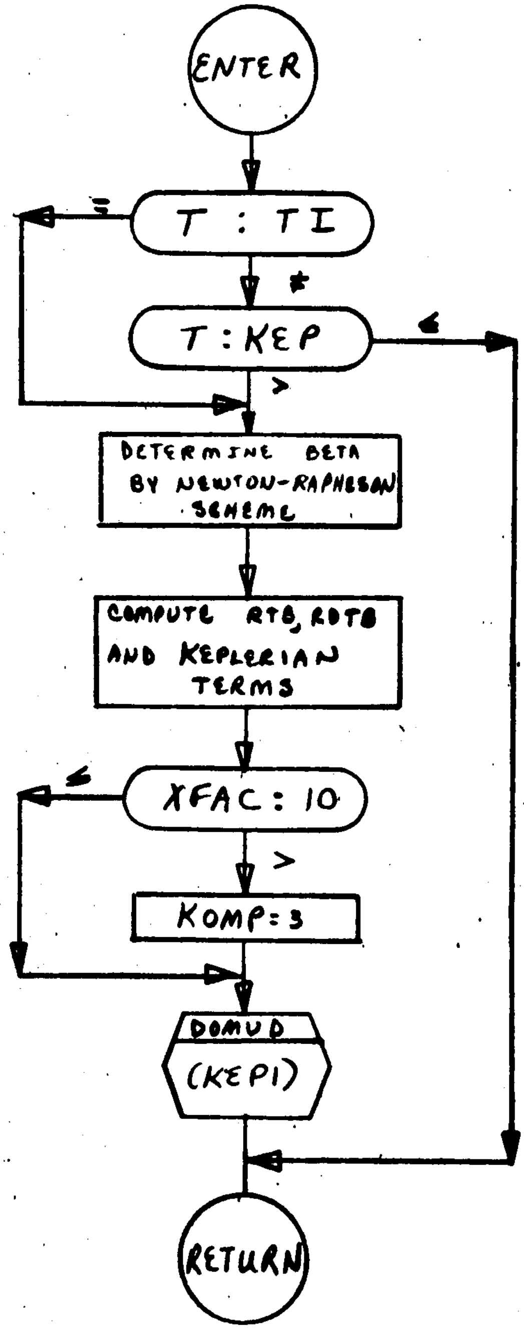
$$\dot{f} = \frac{-\sqrt{\mu}\, S}{r r_o} \tag{10}$$

$$\dot{g} = 1 - \frac{C}{r} \tag{11}$$

$$R(t) = fR_o + g\dot{R}_o \tag{12}$$

$$\dot{R}(t) = \dot{f}R_o + \dot{g}\dot{R}_o \tag{13}$$

27.7 FLOW DIAGRAM - KEPLER



28. Subroutine MAINA

28.1 Purpose

This subroutine handles the main flow of the run.

28.2 Method

MAINA calls subroutines which (a) govern the integration program, (b) determine the time of next activity time (TD), (c) compute the observations, (d) print . It also modifies certain parameters used in the powered flight portion of the program.

28.3 Program References

28.3.1 MAINA is called by:

EXECA

28.3.2 MAINA calls:

CITGRA, CRSTRE, EITGRA, ERSTRE, OBSERA, PDUMP, PFINIT, PRINTA, RECT, SERVCE, STACUL, TIMNGA

28.4 I/O Data

28.4.1 Inputs from COMMON

PFPAR, RCIN, RDCIN, T
CEPID, CWLIN, IPFT, IPS, IRT, IXADD(5), KM, IFL, MAXSTA, MDE, MPLUS1, MPLUS2, MPLUS3, MPLUS4, ONE, PASF, PASS, PRNT3, SPADD(9)

28.4.2 Outputs to COMMON

DELTP, OIEL, RC, RDC, SVL, SVM, T, TAQ, TD, TKEP, TL, TSSA, TSUBN
AMOD, CNT, ICOUNT, IDER, IPFT, KOMP, KSTA, MFLAG, NA, NEL, NUT, PASS, PFON, PURP, TSTRO, VMASS

28.4.3 Other Inputs

None

28.4.4 Other Outputs

28.4.4.1 DUMOBS - logical tape 9 - first word on last record of data tape for MDE = 3.

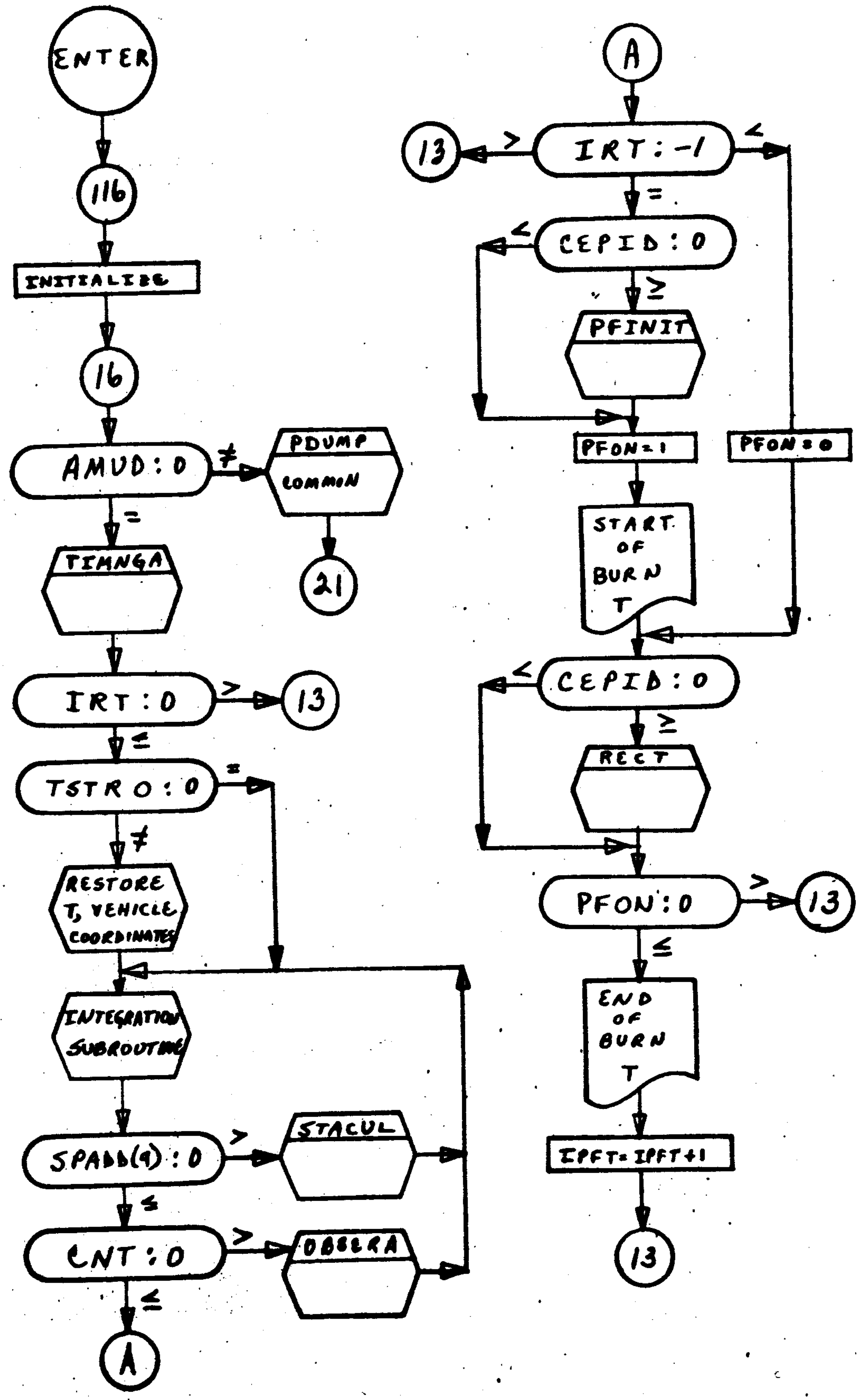
28.4.4.2 T - for "START OF BURN" and "END OF BURN"

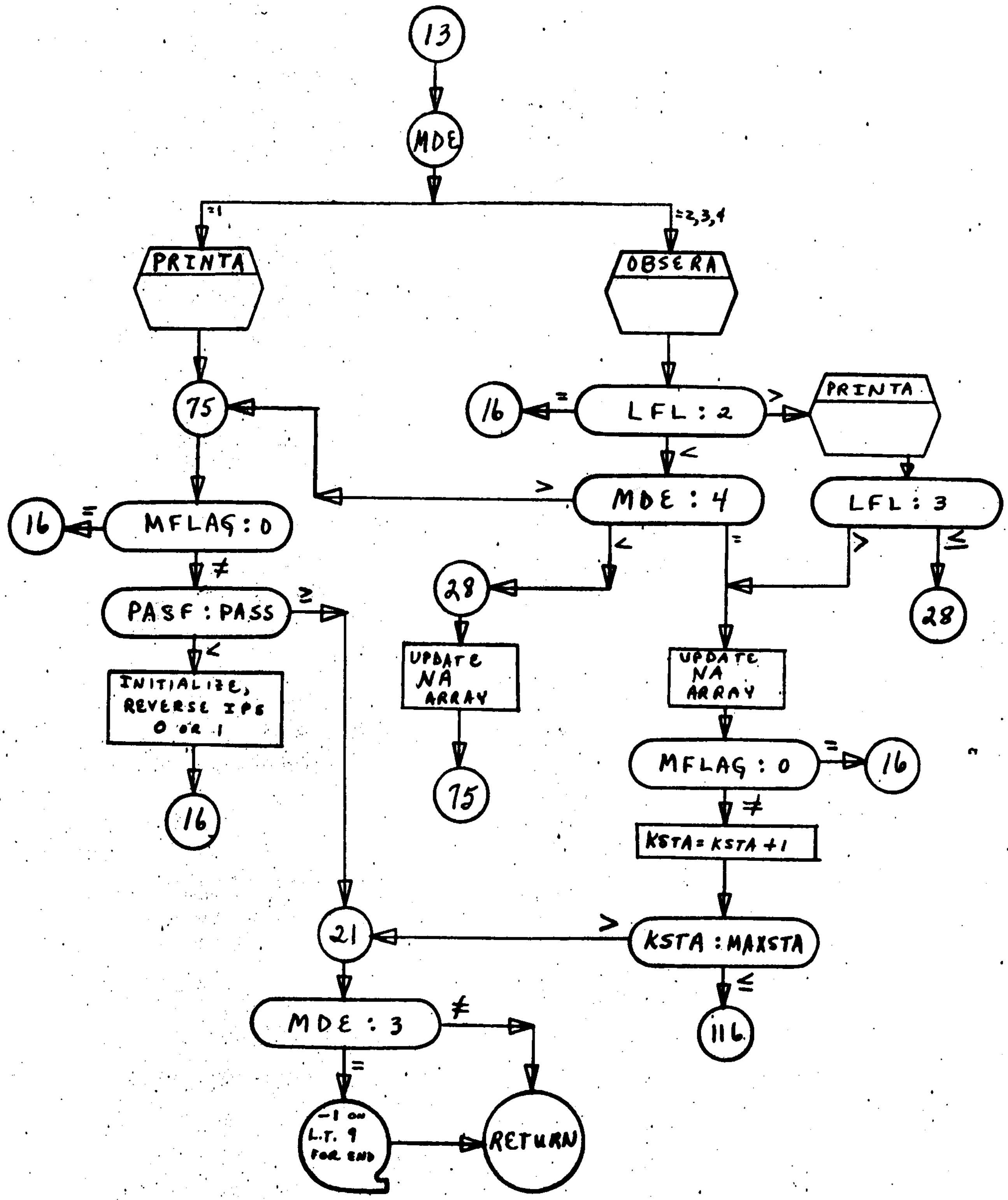
28.5 Symbols Used

None

28.6 Equations Used

None


ENTER
116
INITIALIZE
16
AMUD : 0
≠
PDUMP
COMMON
21
=
TIMNGA
IRT : 0
>
13
≤
TSTRO : 0
=
≠
RESTORE T, VEHICLE COORDINATES
INTEGRATION SUBROUTINE
SPADD(9) : 0
>
STACUL
≤
CNT : 0
>
OBSERA
≤
A
A
IRT : -1
>
13
<
=
CEPID : 0
<
≥
PFINIT
PFON=1
PFON=0
START OF BURN T
CEPID : 0
<
≥
RECT
PFON : 0
>
13
≤
END OF BURN T
IPFT=IPFT+1
13


13
MDE
=1
=2,3,4
PRINTA
OBSERA
75
16
=
LFL : 2
>
PRINTA
<
>
MDE : 4
LFL : 3
16
=
MFLAG : 0
≠
<
=
>
≤
PASF : PASS
≥
28
28
<
INITIALIZE, REVERSE IPS 0 OR 1
UPDATE NA ARRAY
UPDATE NA ARRAY
75
MFLAG : 0
=
16
16
≠
KSTA = KSTA + 1
21
>
KSTA : MAXSTA
≤
MDE : 3
≠
116
=
−1 ON L.T. 9 FOR END
RETURN

29. Subroutine MODELA(K)

29.1 Purpose

This subroutine computes the index of refraction for troposphere or ionosphere.

29.2 Method

When K = 1, compute troposphere model
When K = 2, compute ionosphere model

29.3 Program References

MODELA is called by:

A - OBSERA
B1 - OBSRB1, SBSRB1

29.4 I/O Data

29.4.1 Inputs from COMMON

STACR
F2, HACC, ONE, TWO

29.4.2 Outputs to COMMON

XNNEW

29.4.3 Other Inputs

K

29.4.4 Other Outputs

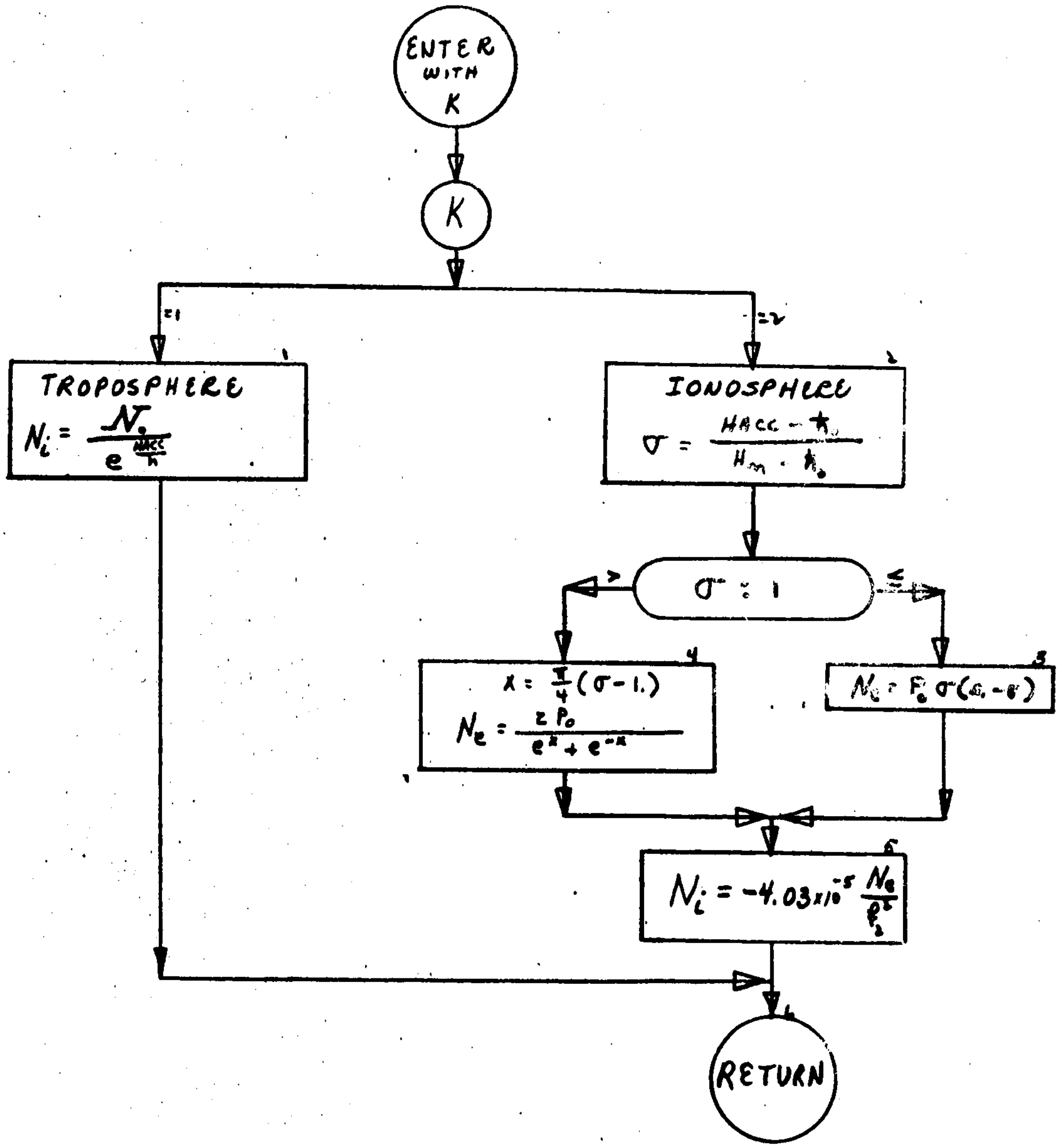
None

29.5 COMMON Symbols Used

TPMAT4

29.6 Equations Used

See Ref. 1, Appendix C.2.2.


ENTER WITH K
K
=1
=2
TROPOSPHERE
IONOSPHERE
>
≤
RETURN

30. Subroutine NUTPRE (K)

30.1 Purpose

This subroutine computes the expressions used for determining Greenwich hour angle, nutation and libration; the gamma matrix; and the precession-nutation matrix.

30.2 Method

When K = 1, the expressions are evaluated

When K = 2, the gamma matrix is computed

When K = 3, the precession-nutation matrix is computed.

30.3 Program References

30.3.1 NUTPRE is called by:

A - CMNOBP, COBDRG, EMNOBP, EOBDRG, STAPOS
B1 - MAINB1 plus A programs above

30.3.2 NUTPRE calls:

DMTML, DOMUD

30.4 I/O Data

30.4.1 Inputs from COMMON

CRAD, DIN, SEC, T, TB, TSVT, TWOPI
HMIN, HRS, KSNAP, MPLUS1, MPLUS3, ONE, SIXTY, SUMCOM, THREE, TWO, TWT4

30.4.2 Outputs to COMMON

CT, D, DT, E, EQ, GAM, GAMM, PRENUT, PSI, TSVT, TTMAT1, TTMAT3, WE, XC, XO

30.4.3 Other Inputs

K

30.4.4 Other Inputs

None

30.5 Symbols Used

30.5.1 COMMON Symbols

TPMAT4

30.5.2 Other Symbols

XNUT1 - BCD word = NUTPRE

30.5.2.1 Expression Portion

G, GP, XL - temporary storage

C (21), S(21), X2C, X2GP, X2L, X3C - temporary storage

30.5.2.2 Gamma Matrix Portion

DI - integer value of D

X3 - time in seconds since launch

DELAPH - contribution to γ due to precession and nutation.

30.5.2.3 Precession-Nutation Portion

CONV - conversion factor

TPR, TZP - time parameters

30.6 Equations Used

See Ref. 1, Appendix A, for equations used for nutation. The equations given there for precession have been replaced by the following set.

$$[P] = \begin{bmatrix} \cos\delta_0 \cos\theta \cos z - \sin\delta_0 \sin z & -\sin\delta_0 \cos\theta \cos z - \cos\delta_0 \sin z & -\sin\theta \cos z \\ \cos\delta_0 \cos\theta \sin z + \sin\delta_0 \cos z & -\sin\delta_0 \cos\theta \sin z + \cos\delta_0 \cos z & -\sin\theta \sin z \\ \cos\delta_0 \sin\theta & -\sin\delta_0 \sin\theta & \cos\theta \end{bmatrix}$$

where

$$\delta_0 = (2304.250'' + 1.396'' T_0)\, T + .302''\, T^2 + .018''\, T^3$$

$$z = \delta_0 + .791''\, T^2$$

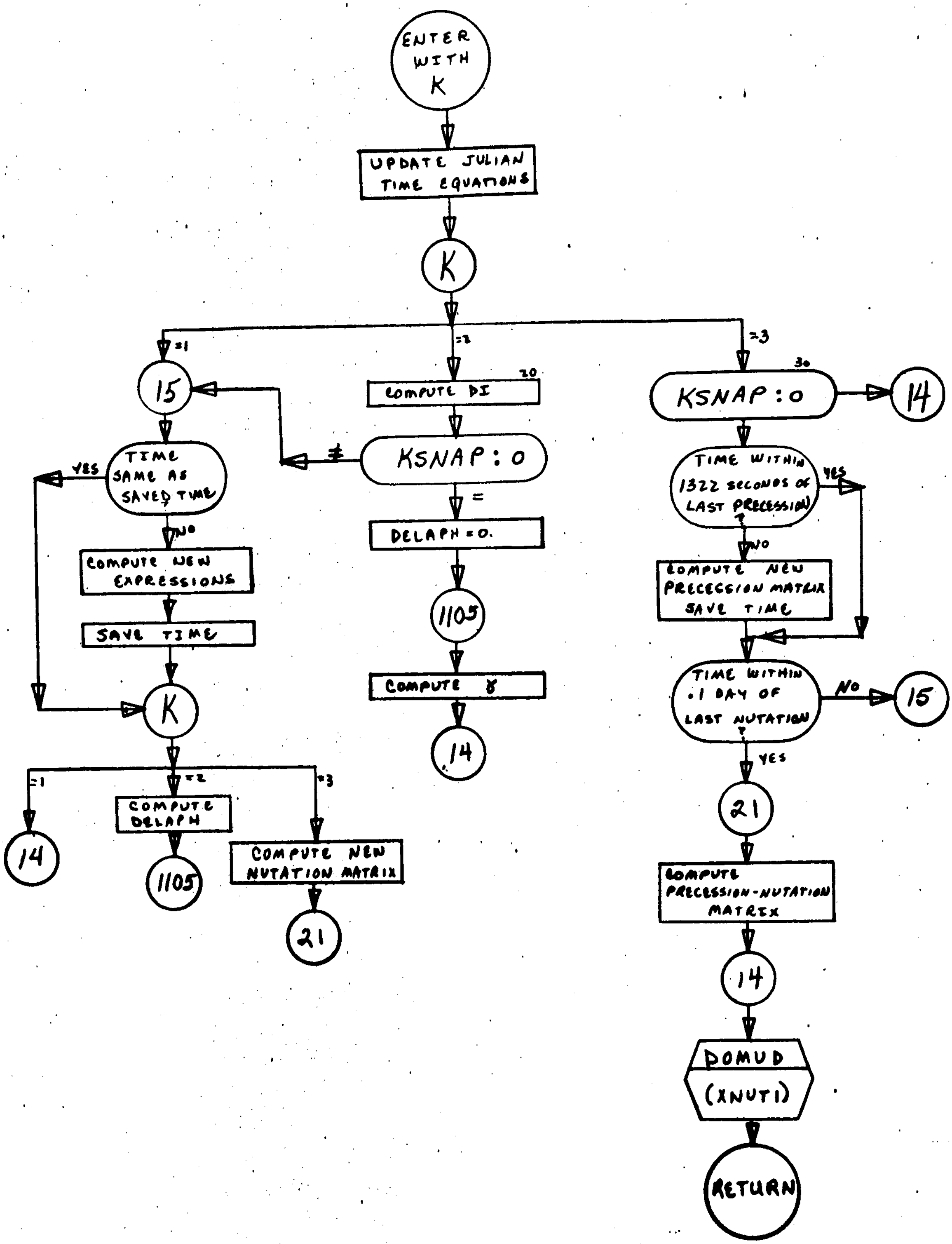
$$\theta = (2004.682'' - .853''\, T_0)\, T - .426''\, T^2 - .042''\, T^3$$

The times T_0 and T are related to program times by the following expressions:

$$T_0 = .499017330 + 1.000021358\ T_B$$

$$T = 1.000021358\ DT$$

30.7 FLOW DIAGRAM - NUTPRE



31. Subroutine OBD

31.1 Purpose

This subroutine computes observations from on board instrumentation.

31.2 Method

The subroutine uses present position of vehicle with respect to reference bodies, landmarks, or ground stations to determine observations.

31.3 Program References

31.3.1 OBD is called by:

OBSERA

31.3.2 OBD calls:

CMNOBP, DDOT, EMNOBP, SERVCE, STAPOS

31.4 I/O Data

31.4.1 Inputs from COMMON

CPOS, PI, PROPNL, RC, STAC
CEPID, IPLNT, ISTAR, MAXLUN, MAXSTA, MPLUS1, MPLUS2, MPLUS3, MWREF, ONE,
POSLUN, RADII, STAR, TWO

31.4.2 Outputs to COMMON

OBSPIS, STAC, STALN, STALT, YCOM
IXADD(13), KSTA, SPADD(8), SPADD(10)

31.4.3 Other Inputs and Outputs

None

31.5 Symbols Used

31.5.1 COMMON Symbols

TPMAT4, TPMAT9, TPMTFO

31.5.2 Other Symbols

RTEMP - temporary storage

RTEMP1 - temporary storage

YRTEMP(6) - temporary storage

YTEMP(2) - temporary storage

ILUNE - index for lunar landmark indication

IST - flag

KJ - flag

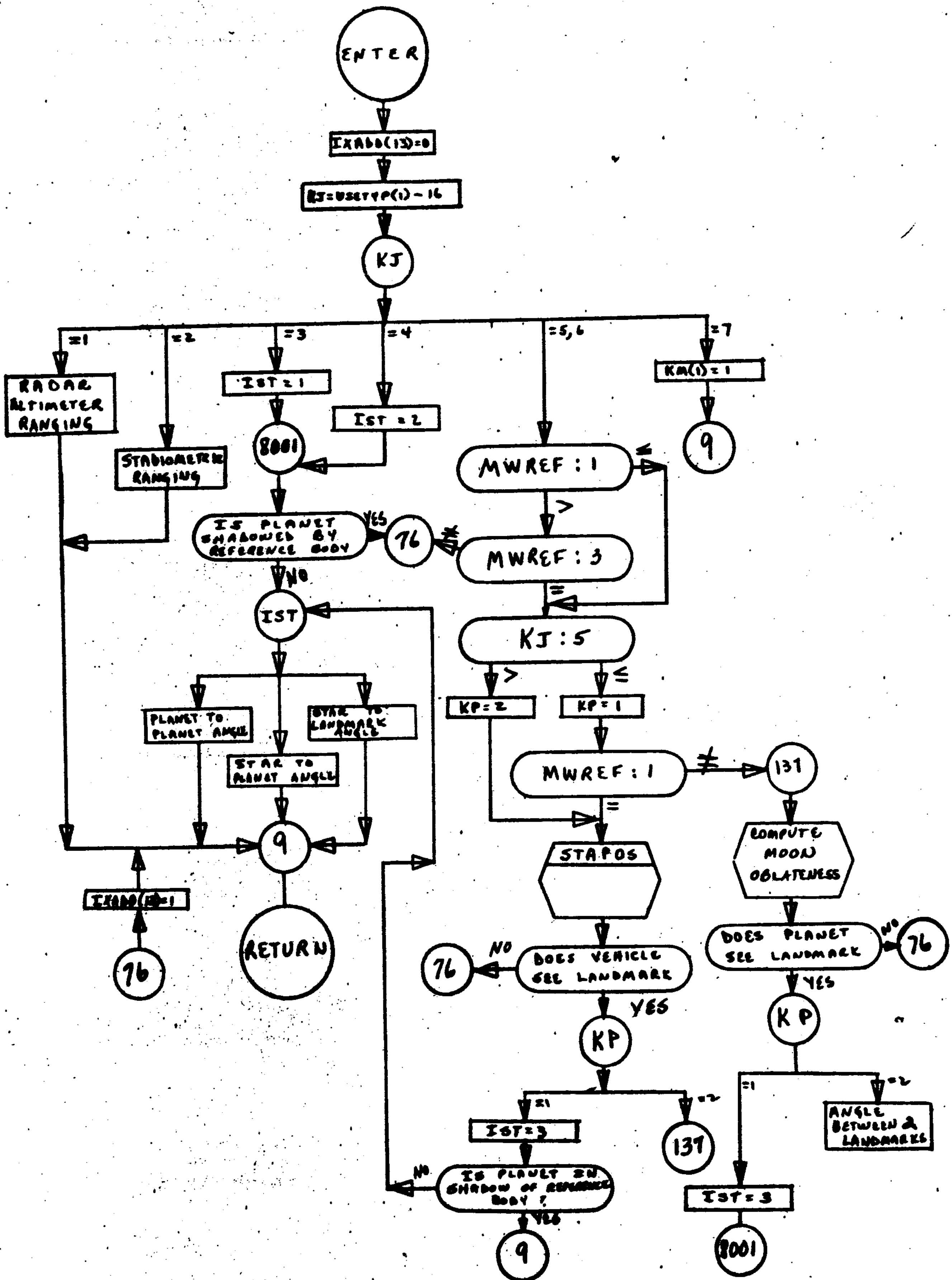
KLIBRS - saved KLIBR

KP - flag

31.6 Equations Used

See Ref. 1., Section 6.2.

31.7 FLOW DIAGRAM - OBD



32. Subroutine OBSERA

32.1 Purpose

This subroutine computes the observables as seen from a given ground station. Corrections to the propagation of electromagnetic waves through a refractive medium can be made, if desired. In the A4 mode, it also computes the time of passage, which is the total time the vehicle is in sight of the station on each pass.

32.2 Method

Given present vehicle location and ground station location, both referenced to inertial space, the observed values are computed. When specified, refraction corrections are included.

32.2 Program References

32.3.1 OBSERA is called by:

MAINA

32.3.2 OBSERA calls:

ATIM, CINT, CRSTRE, DDOT, DMTML, DOMUD, EINT, ERSTRE, FIX, KEPLER, MODELA, OBD, SERVCE, STAPOS

32.4 I/O Data

32.4.1 Inputs from COMMON

DOMB, CPOS, CVEL, DTI, EMIN, EPSSQ, ERAD, OVB, PRENUT, RC, RDC, RDTB, RTB, STAC, STAHT, STALT, STAOR, T, TAQ, TPMAT1 (from STAPOS), TWOPI, TZHRS, YCOM
CEPID, DH1, DH2, FDOWN, FUP, H2, H4, IXADD (13), KM, KRF, KS2BY, KSTA, MDE, MINUS1, MPLUS1, MPLUS2, MPLUS3, MPLUS4, NEL, ONE, SPADD (8), SPADD (10), TSTRO, TWO, TYPE

32.4.2 Outputs to COMMON

DTI, OBSPLS, OLEL, ORM, OVB, RC, RCMSC, RDC, SAVD, SVL, SVM, T, TSSA, YCOM
AMUD, DELTA, F1, F2, ICOUNT, KM, KSTA, LFL, LML, NCDST, NEL, NUMDAT, USETYP

32.4.3 Other Inputs

None

32.4.4 Other Outputs

32.4.4.1 TOTP - total time of passage

32.4.4.2 Logical tape 9 - observable information-binary

ANS - double precision time

LTEMP - packed word of data types

(TEMP (I), I = 1, 4) - values of the 4 observables

LTEMP1 - packed word for quality bits = 0

ICOUNT - count number of data pt on the tape.

32.5 Symbols Used

32.5.1 COMMON Symbols

HACC, TPMAT1, TPMAT2, TPMAT4, TPMAT5, TPMAT9, TPMT10, XNNEW

32.5.2 Symbols used in Refraction Portion-all single precision

YDOT - component of vehicle velocity vector projected into the plane formed by vehicle, station and earth center.

CD - cosine of DELTA

CTNEW - cosine θ_i, θ = the current elevation angle during iterations

CTPREV - cosine θ_{i-1} during iterations

DISCRM - $1 - \cos^2\theta$ $(\sin^2\theta)$

DRACC - accumulated range correction

DTEMP - intermediate DRACC's

ER - error angle at the center of the earth

F22 - square of the down frequency

GMACC - accumulated bending angle of the refracted ray

HLAST - final Δ h, if increment not exact in troposphere or ionosphere

HT - altitude of vehicle above sea level

HTEMP - current span of incrementation for a specific layer

ICODE - flag for exact or non-exact incrementation
= 1, non-exact
= 2, exact, or HLAST has been used

IFG - flag word for model

ILAYER - flag for which of 4 atmospheric layers vehicle is in
= 1, troposphere
= 2, lower vacuum
= 3, ionosphere
= 4, upper vacuum

JLAYER - flag for which layer is currently being computed
= 1, troposphere
= 2, ionosphere

NCORR - flag for which errors are to be computed
= 1, all
= 2, Range only
= 3, skip Range
= 4, none

NDH - number of times to increment within a layer

RATIO - round trip frequency ratio

RDOTER - refraction error in range rate

RFR1 - BCD work = RFRCT1

SAVF2 - saved value of F2

SD - sine of DELTA (corrected elevation angle)

SNNEW - index of refraction, n_i , during iterations

SNPREV - index of refraction, n_{i-1} , during iterations

STNEW - sine θ_i during iterations

STPREV - sine θ_{i-1} during iterations

TEST1 - BCD word = RFR2

TEST2 - BCD work = RFR3

TTNEW - tan θ_i during iterations

TTORIG - tan θ_0 , initial elevation angle

TTPREV - tan θ_{i-1} during iterations

XDH - current altitude increment (Δ h)

XN - floating point NDH

XNORIG - refractivity at the station

XNPREV - refractivity, $\mathcal{N}_{i-1}$ during iterations

32.5.3 Other Symbols

ALPNM (3,3) - transformation matrix from station topocentric coordinates to true topocentric coordinates

CA - cosine YCOM (1)

CE - cosine YCOM(2)

DEN - magnitude of the component of ORM projected onto the horizontal plane

OREBD - east component of ORM in topocentric system

ORHSD - up component of ORM in topocentric system

ORM2 - square of ORM

ORNSD - north component of ORM in topocentric system

SA - sine YCOM (1)

SE - sine YCOM (2)

SYC - saved value of YCOM (2)

TEMAL (8) - temporary allocations

VCMSC (6) - vector between reference body center and vehicle

YTEMP (2) - temporary YCOM's

DATTYP (4) - array of indices for data types used

FLAG5 - flag word

INDEX - index for observables in STAOR array

ISTS - saved value of KSTA

KTEMP - saved value of KSTA

KSTAT(S) - (data) - station numbers of paired DSN stations

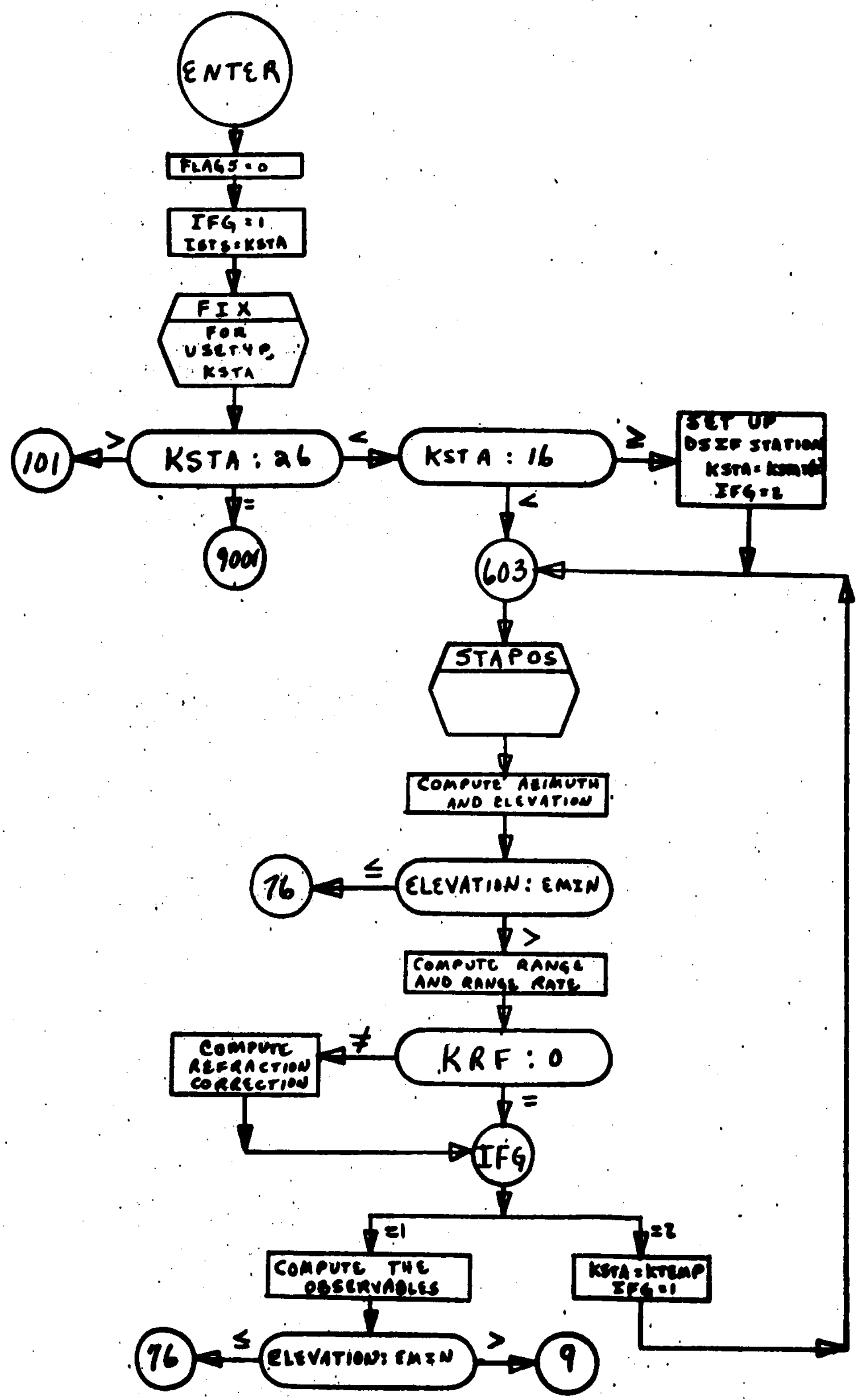
N - index for number of data types

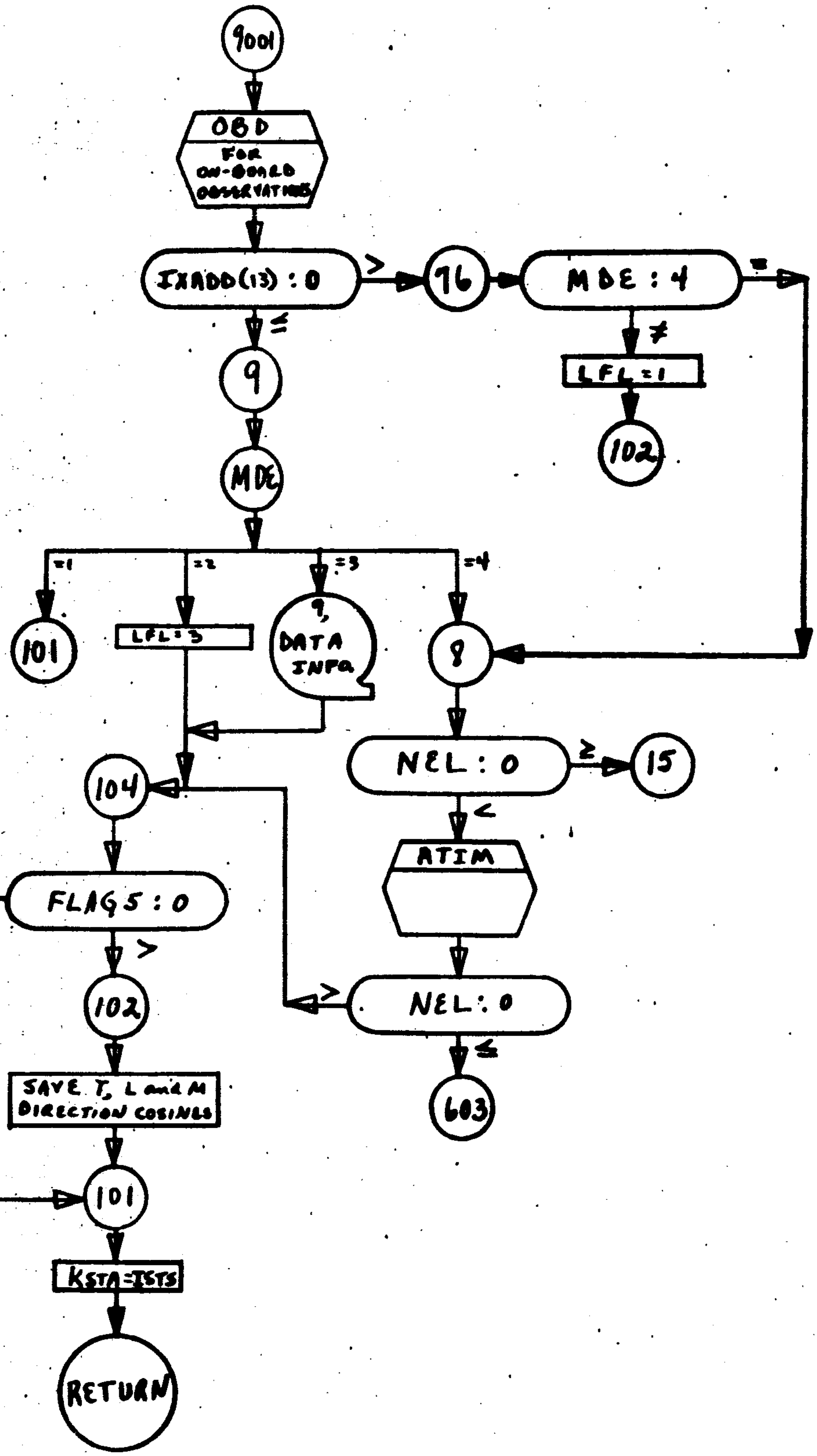
32.6 Equations Used

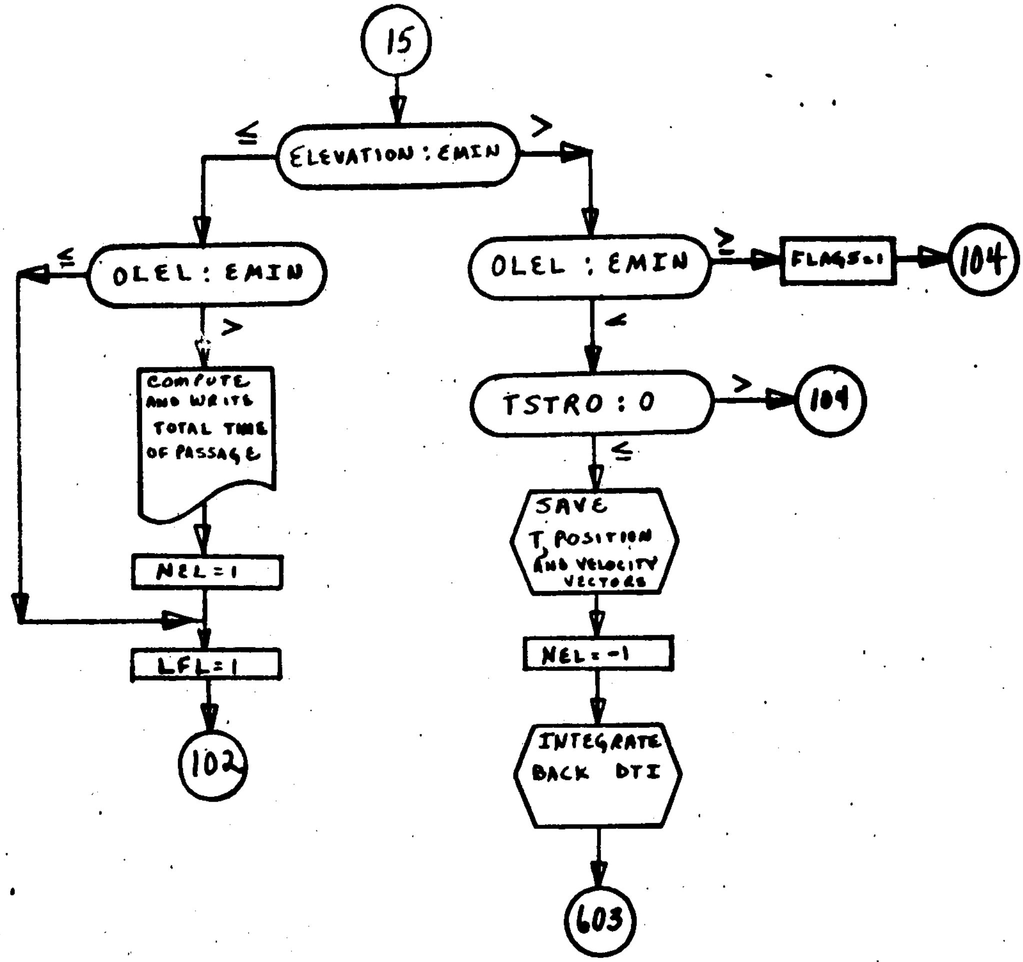
See Ref. 1, Section 6.2

See Ref. 1, Appendix C for Refraction Correction

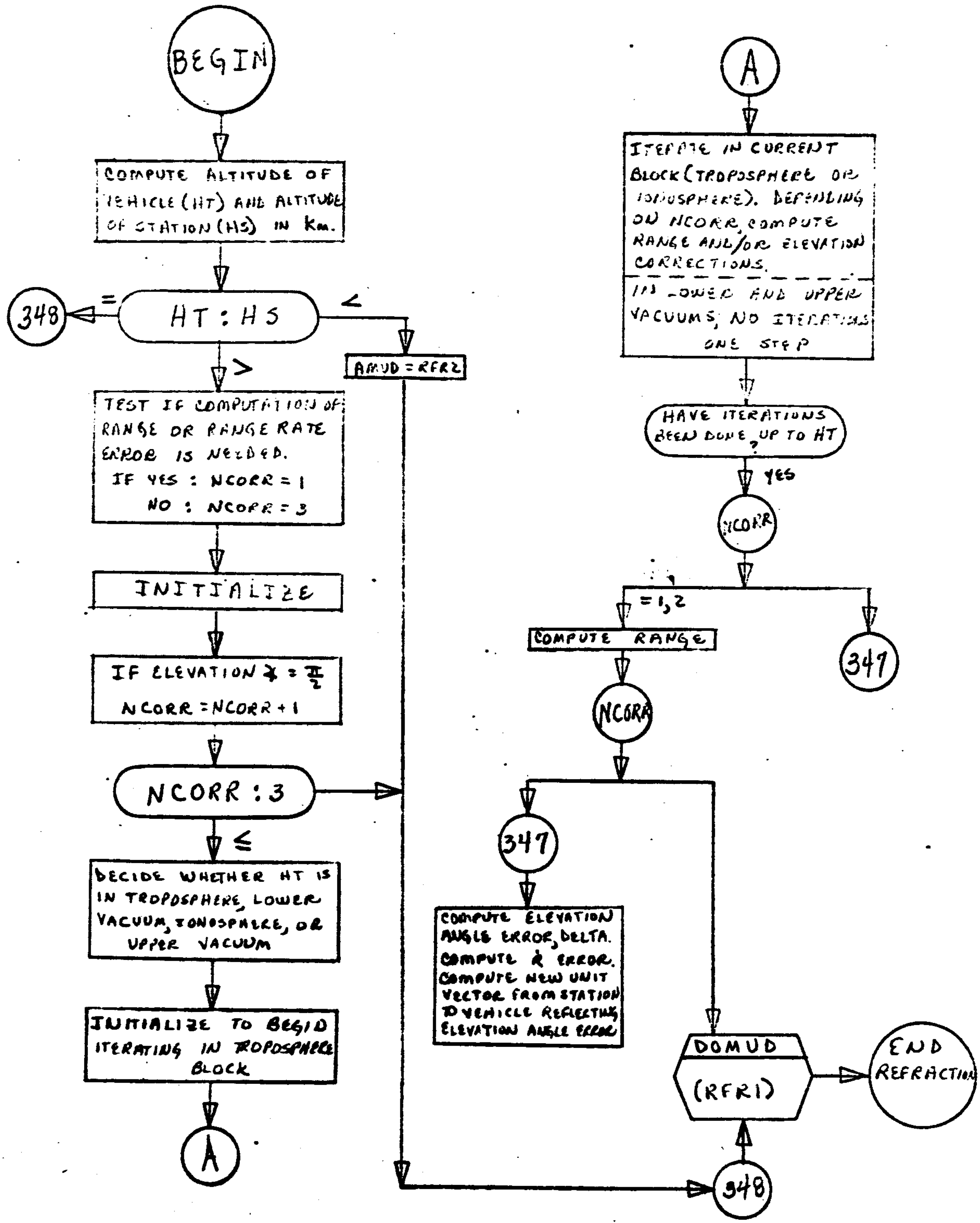
32.7.1 Flow Diagram - OBSERA




9001
OBD
FOR ON-BOARD OBSERVATIONS
IXADD(13) : 0
>
≤
96
MDE : 4
=
≠
LFL=1
102
9
MDE
=1
=2
=3
=4
101
LFL=3
9, DATA INFO
8
NEL : 0
≥
15
<
ATIM
104
FLAG5 : 0
≤
>
102
NEL : 0
>
≤
603
SAVE T, L and M DIRECTION COSINES
101
KSTA=ISTS
RETURN


15
ELEVATION : EMIN
≤
>
OLEL : EMIN
≤
>
COMPUTE AND WRITE TOTAL TIME OF PASSAGE
NEL=1
LFL=1
102
OLEL : EMIN
≥
FLAG=1
104
<
TSTRO : 0
>
109
≤
SAVE T, POSITION AND VELOCITY VECTORS
NEL=-1
INTEGRATE BACK DTI
603

32.7.2 Flow Diagram - REFRACTION Portion



33. Subroutine PFINIT

33.1 Purpose

This subroutine performs initialization procedures at the entry of a burn period.

33.2 Method

The subroutine determines coefficients of six Chebyshev polynomials which are valid for the first burn period.

33.3 Program References

33.3.1 PFINIT is called by:

A - MAINA

B1 - MAINB1

33.3.2 PFINIT calls:

OVERFL

33.4 I/O Data

33.4.1 Inputs from COMMON

HMU, PFPAR, RC, RDC

FPK, IPFT, MPLUS1, MPLUS2, ONE, THREE TWO

33.4.2 Outputs to COMMON

RDTB, RTB, TMAXPF, TSTART, U

AMUD, LIMIT2

33.4.3 Other Inputs

None

33.4.4 Other Outputs

Various intermediate calculations.

33.5 Symbols Used

33.5.1 COMMON Symbols

TPMAT4, TPMAT5

33.5.2 Other Symbols

AVTMX - Absolute value of total length of burn.

CK(30) - Array of C_k values ($K \neq 0$)

CKZERO(30) - Array of C_k values ($K = 0$)

CLOWER - Floating point integer for evaluating CK

CUPPER - Floating point integer for evaluating CK

FACTOR - Temporary variable

Q - Floating point integer

SF - Scale factor = 1. x 10^6

SFSQU - Scale factor = 1. x 10^{12}

SUM, SUMA, SUMB, SUMC - Summations

TEMP - Temporary variable

TMAXM - T_{max} to current power.

TMAXSQ - Square of total length of burn.

V(62,3) - Array of thrust coefficients

INDEX, INDEXP, INDEXQ, JL, KPLUSI, LIMIN1, LIMIN2, LIMIT1, LMIN1,

LPLUS2, M, NT, NT1, NT2, NTZ - variable used as indices and limits

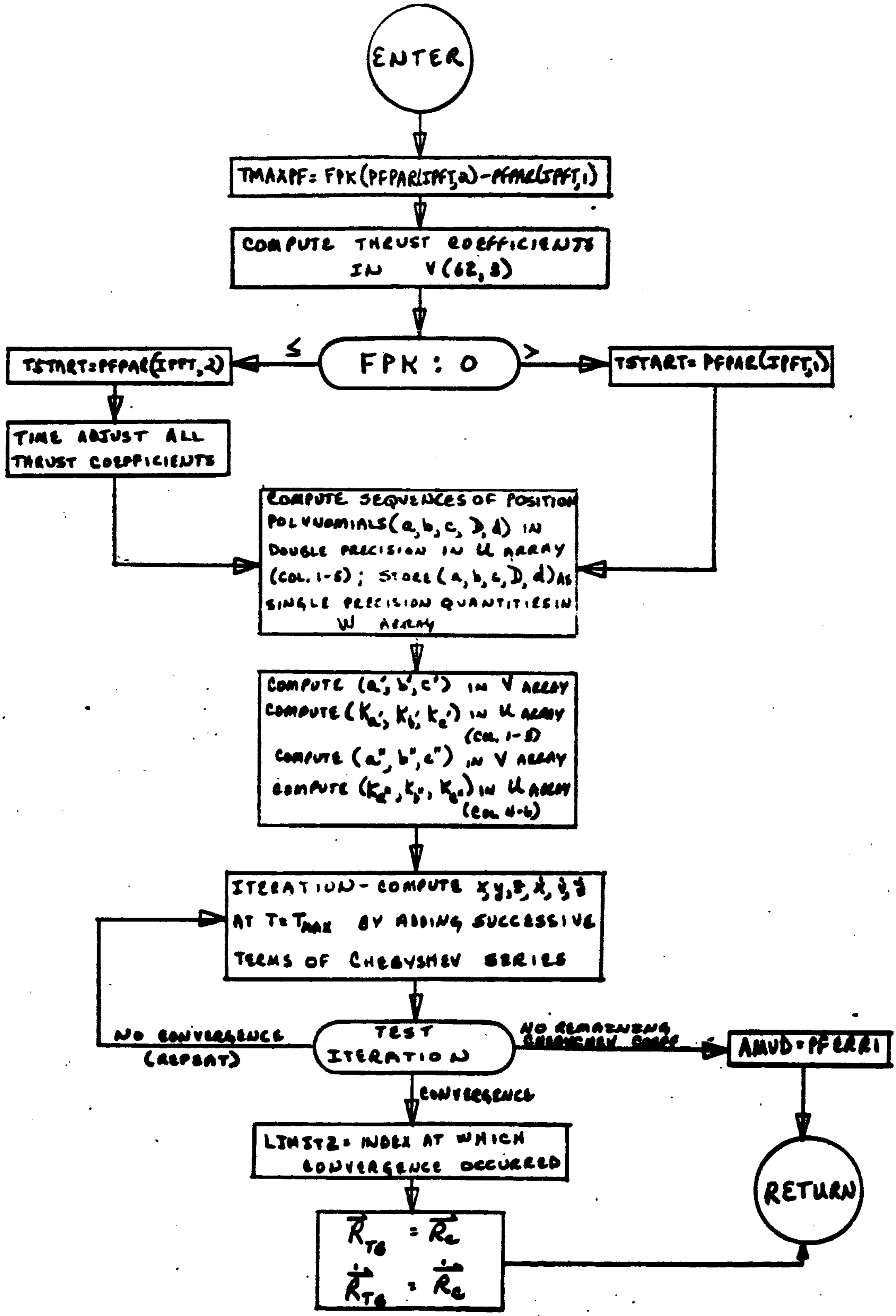
PFERR1 - BCD word = PFERR1

VOFI, VOFJ, VOFK, VOFM - floating point integer.

W(61,5) - Array of position polynomials

33.6 Equations Used

See Reference 1, Appendix B and Section 3.4


ENTER
TMAXPF = FPK (PFPAR(IPFT,2) - PFPAR(IPFT,1))
COMPUTE THRUST COEFFICIENTS IN V(62,3)
FPK : 0
≤
>
TSTART = PFPAR(IPFT,2)
TSTART = PFPAR(IPFT,1)
TIME ADJUST ALL THRUST COEFFICIENTS
COMPUTE SEQUENCES OF POSITION POLYNOMIALS (a, b, c, D, d) IN DOUBLE PRECISION IN U ARRAY (COL. 1-5); STORE (a, b, c, D, d) AS SINGLE PRECISION QUANTITIES IN W ARRAY
COMPUTE (a', b', c') IN V ARRAY
COMPUTE (Ka', Kb', Kc') IN U ARRAY (COL. 1-3)
COMPUTE (a", b", c") IN V ARRAY
COMPUTE (Ka", Kb", Kc") IN U ARRAY (COL. 4-6)
ITERATION - COMPUTE x, y, z, ẋ, ẏ, ż AT T = TMAX BY ADDING SUCCESSIVE TERMS OF CHEBYSHEV SERIES
TEST ITERATION
NO CONVERGENCE (REPEAT)
NO REMAINING CHEBYSHEV TERMS
AMUD = PFERR1
CONVERGENCE
LIMST2 = INDEX AT WHICH CONVERGENCE OCCURRED
$\vec{R}_{TB} = \vec{R}_e$
$\dot{\vec{R}}_{TB} = \dot{\vec{R}}_e$
RETURN

34. Subroutine PFLGHT

34.1 Purpose

This subroutine computes the effect of a thrust perturbation. It is used only in the Encke method. The formulation used was developed because it has, as an extension, an analytic state transition matrix which can be used in statistically determining powered flight parameters.

34.2 Method

The thrust acceleration vector at the initial burn time, the vehicle mass and mass rate are converted to a set of coefficients for 6 Cheby shev polynomials. These coefficients are determined in PFINIT. The subroutine, PFLGHT, uses these coefficients to describe the powered flight trajectory as a function of time, Effectively, the subroutine replaces KEPLER in Encke's method. Integration of the equations of motion continues exactly as if powered flight was not involved.

34.3 Program References

34.3.1 PFLGHT is called by:

EITGRA

34.3.2 PFLGHT calls:

SERVCE

34.4 I/O Data

34.4.1 Inputs from BLANK COMMON

T

FPK, MPLUS2, ONE, TWO

34.4.2 Inputs from BLOCK COMMON - /CPF/

U, TMAXPF, TSTART

LIMIT2

RDTB, RTB

34.4.4 Other Inputs and Outputs

None

34.5 Symbols Used

TEMP - Saved value of TSTAR

TN - Time from start of burn

TPRIME - Relative time factor

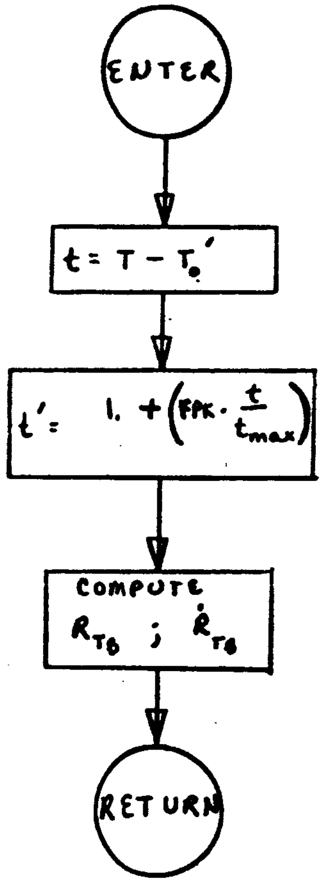
TSTAR - Relative time factor

TSTARP - Relative time factor

34.6 Equations Used

See Ref 1, Section 3.4

34.7 FLOW DIAGRAM - PFLGHT



35.1 Purpose

This subroutine prints out current trajectory information.

35.2 Method

Depending on whether the time entered corresponds to a print time, the program checks each of the 10 elements in the IPSEC array. If the value is > 0, the corresponding section is printed.

To determine whether it is a print time, the subroutine first checks to see whether the present time is within the print portion (DTPI) of a total print period (TAU). If not, no printing is done. If so, it next checks the value of the print interval within DTPI (PRATE). If it is negative, it always prints. If it is positive, and it is the first time into the present print period, it prints, otherwise no printing is done. When MDE = 1 or 4, printing occurs at each entry to the routine.

35.3 Program References

35.3.1 PRINTA is called by:

MAINA

35.3.2 PRINTA calls:

DDOT, DOMUD, SERVCE

35.4 I/O Data

35.4.1 Inputs from COMMON

CONST, CPOS, CRAD, CVEL, EPSSQ, GAMM, PRENUT, RC, RDC, SCALE, STAC, T, TMAX, TWOPI, YCOM

CWLIN, DTPI, IXADD(10), KSTA, MDE, MINUSI, MPLUS1, MPLUS2, MPLUS4, MWREF, NUMDAT, NUMT, NYEARP, ONE,PRATE, PVALPH, SIXTY, STANM, TAU, THREE, TWO TWT4, TZERO, USETYP

35.4.2 Outputs to COMMON

HMU, SQTMU

AMUD, IXADD(10), FKPR

35.4.3 Other Inputs

None

35.4.4 Other Outputs

See Ref. 2, Section 3.1

35.5 Symbols Used

35.5.1 COMMON Symbols

TPMAT4, TPMAT5, TPMAT6, TPMAT7, TPMAT8, TPMAT9

35.5.2 Other Symbols

DATYPE(4) - Stores BCD words of the observation types used.

ESPAL(4,7,2) - (Data) - BCD words for use in printing section 6.

FTAU - Fractional part of print period (TAU)

IDAYS - Integer number of days from beginning of launch year

IDT - Fractional portion of current time in integer form.

IHRS - Integer number of hours from beginning of launch year.

IMIN - Integer number of minutes from beginning of launch year.

IPNT - Current print section

IT - Current time in integer form, also used as temporary storage

K - Current data type

KJP - Indicator for type of on-board observation.

KPR - Indicator to determine next print time.

NCODE - Index for CPOS and CVEL for printing section 9.

NP1 - Star number of on-board observation

NP2 - Station number of on-board observation.

NUMTAU - Number of the print period being processed

OBTYPE (25) - (Data) - BCD types, for printing Sections 2 and 10

OBUNIT (25) - (Data) - BCD units, for printing Section 10

OSCUL1 - BCD word = OSCUL1

OSCUL2 - BCD word = OSCUL2

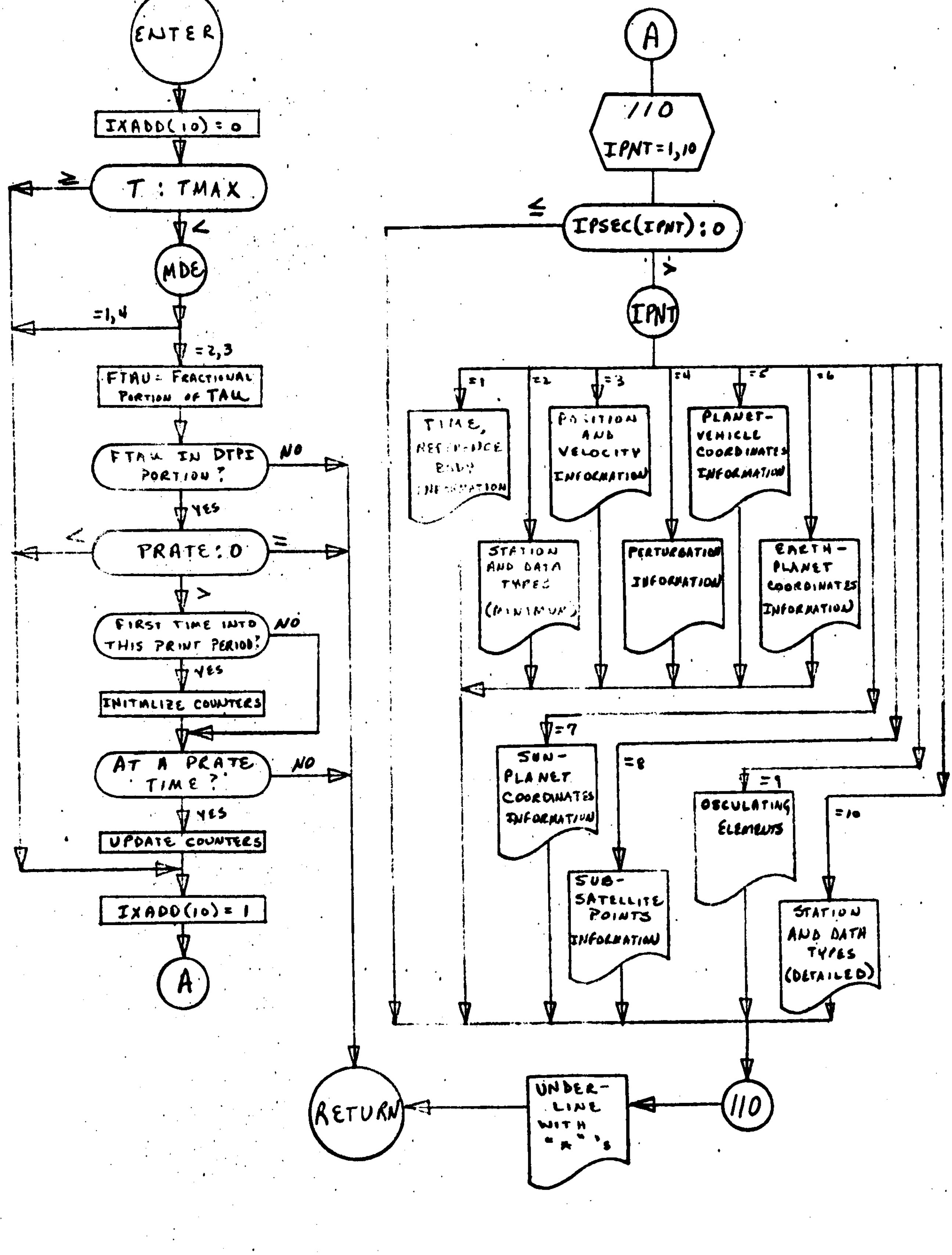
POST - Positive value of T

PVAL(4,7) - (Data) - BCD words for printing Section 5

REFBOD(7) - (Data) - BCD words for printing Section 1

35.6 Equations Used

Equations used for the osculating elements and subsatellite point computations follow standard equations.


ENTER
IXADD(10) = 0
T : TMAX
≥
<
MDE
=1,4
=2,3
FTAU = FRACTIONAL PORTION OF TAU
FTAU IN DTPI PORTION?
NO
YES
PRATE : 0
<
=
>
FIRST TIME INTO THIS PRINT PERIOD?
NO
YES
INITIALIZE COUNTERS
AT A PRATE TIME?
NO
YES
UPDATE COUNTERS
IXADD(10) = 1
A
A
110
IPNT=1,10
IPSEC(IPNT) : 0
≤
>
IPNT
=1
=2
=3
=4
=5
=6
=7
=8
=9
=10
TIME, REFERENCE BODY INFORMATION
POSITION AND VELOCITY INFORMATION
PLANET-VEHICLE COORDINATES INFORMATION
STATION AND DATA TYPES (MINIMUM)
PERTURBATION INFORMATION
EARTH-PLANET COORDINATES INFORMATION
SUN-PLANET COORDINATES INFORMATION
OSCULATING ELEMENTS
SUB-SATELLITE POINTS INFORMATION
STATION AND DATA TYPES (DETAILED)
RETURN
UNDER-LINE WITH "*"'s
110

36. Subroutine RECT

36.1 Purpose

This subroutine computes the parameters pertinent to a rectification in Encke's method.

36.2 Method

The two-body position and velocity vectors are equated to the true position and velocity vectors. In addition, these components are saved. Perturbations in position and velocity are set equal to zero, and elements used by the KEPLER subroutine are computed.

36.3 Program References

36.3.1 RECT is called by:

A - EITGRA, MAINA
B1 - EITGRA, MAINB1

36.3.2 RECT calls:

DDOT, DOMUD

36.4 I/O Data

36.4.1 Inputs from COMMON

DYN, RC, RDC, T
KOMP, MPLUS2, MWREF, ONE, TWO

36.4.2 Outputs to COMMON

CZ, DZ, HMU, RA, RDI, RDTB, RI, RTB, SQTMU, TH, TI
CWLIN, IP, KOMP, TSTRO

36.4.3 Other Inputs

None

36.4.4 Other Outputs

T,KOMP - indicator for cause of rectification

36.5 <u>Symbols Used other than COMMON</u>

RECT1 - BCD word = RECT

RECTT - saved time

36.6 <u>Equations Used</u>

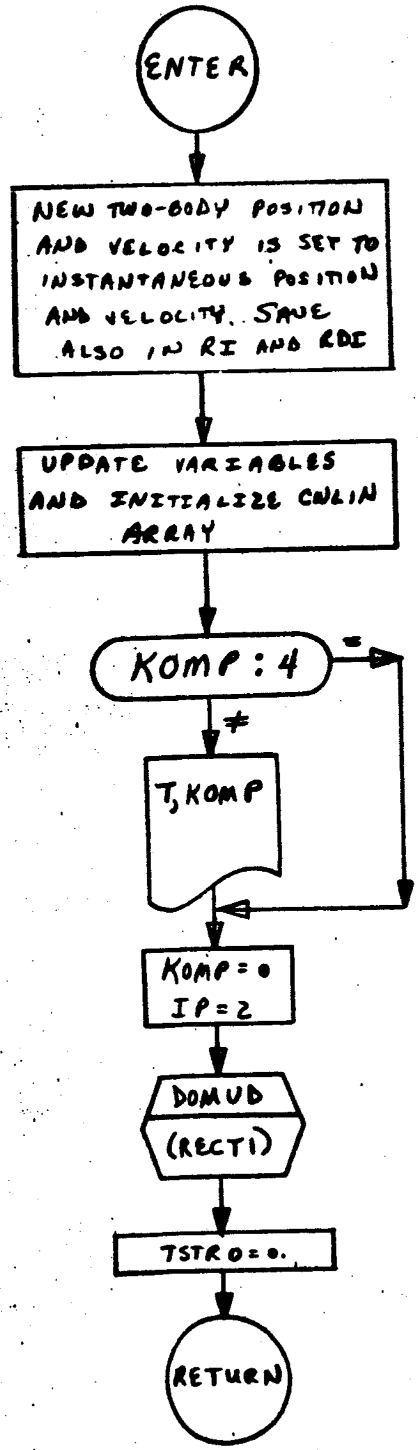
$$SQTMU = \sqrt{HMU}$$

$$D_o = R_I \cdot \dot{R}_I / \mu$$

$$RA = \frac{2}{|R_I|} - \frac{|\dot{R}_I|^2}{\mu} = \frac{1}{a}$$

$$C_o = 1 - \frac{|R_I|}{a}$$

36.7 FLOW DIAGRAM - RECT



37. Subroutine SERVCE (A,B,C,I)

37.1 Purpose

To compute the cross product of 2 vectors A and B stored in C and/or the magnitude, magnitude squared and cubed of C in C(4-6).

37.2 Method

When I = 1, the cross product of A and B is stored in C(1-3) and continues as when I = 2.

When I = 2, the magnitude cubed, magnitude, and magnitude squared is stored in C(4-6), respectively.

37.3 Program References

SERVCE is called by most subroutines in A, B1 and B2 programs.

37.4 I/O Data

37.4.1 Inputs

A - first matrix (not used when I = 2)

B - second matrix (not used when I = 2)

C(1-3) - X,Y,Z coordinates (input when I = 1)

I - flag word (see above)

N.B. when I = 2, the input vector C must be in the third argument

37.4.2 Outputs

C(1-3) - X,Y,Z coordinates (when I = 1)

C(4-6) - See "Equations Used"

37.5 Symbols Used

X - temporary storage

37.6 <u>Equations Used</u>

$$C(1) = A(2) \cdot B(3) - B(2) \cdot A(3)$$

$$C(2) = A(3) \cdot B(1) - B(3) \cdot A(1)$$

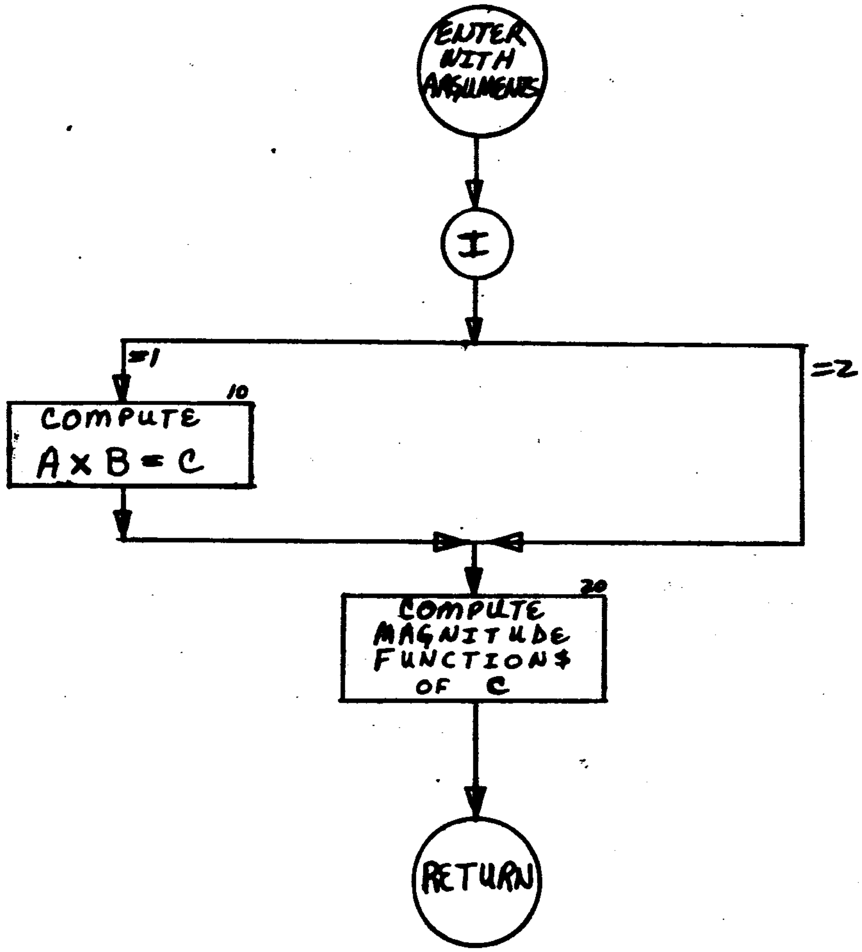
$$C(3) = A(1) \cdot B(2) - B(1) \cdot A(2)$$

$$C(4) = \left[C(1)^2 + C(2)^2 + C(3)^2\right]^{3/2}$$

$$C(5) = \left[C(1)^2 + C(2)^2 + C(3)^2\right]^{\frac{1}{2}}$$

$$C(6) = C(1)^2 + C(2)^2 + C(3)^2$$

37.7 FLOW DIAGRAM - SERVCE



38. Subroutine STACUL

38.1 Purpose

This subroutine determines the time of occultation (YCOM(23)). One of two types of occultation may be considered, vehicle or star occultation.

38.2 Method

A Newton-Raphson iteration is used on the two-body solution to determine the time of occultation. When considering star occultation, the occulting body is the reference body, except in the earth-moon system, in which either the moon or the earth can do the occulting. Vehicle occultation occurs only in moon reference. Up to three different ground stations may be considered for occultation.

38.3 Program References

38.3.1 STACUL is called by:

A - MAINA

B1 - MAINB1

38.3.2 STACUL calls:

DDCT, DMTML, EPHEM, KEPLER, SERVCE, STAPOS

38.4 I/O Data

38.4.1 Inputs from COMMON

CPOS, CVEL, DPADD(18), EMIN, OBSPLS, OVB, PRENUT, RC, RDC, RDTB, RTB, STAC, T, TH, TPMAT1 (from STAPOS), YCOM

FPK, ISTAR, IXADD(15), IXADD(16), IXADD(20), KOMP, KSTA, MPLUS1, MPLUS2, MPLUS3, MWREF, ONE, PURP, RADII, SPADD(7), STAR, TWO

38.4.2 Outputs to COMMON

DPADD(18), T, TH, YCOM

IXADD(14), KOMP, KSTA, SPADD(8), SPADD(10), SPADD(11)

38.4.3 Other Inputs and Outputs

None

38.5 Symbols Used

38.5.1 COMMON Symbols

TPMAT2, TPMAT6, TPMAT7, TPMAT8, TPMAT9

38.5.2 Other Symbols

TSTT - saved T

ICT - count on number of stations being processed

IFLG - flag

= 1, Star occultation, reference body is the occulting body

= 2, Star occultation, non-reference body is the occulting body

= 3, Vehicle occultation

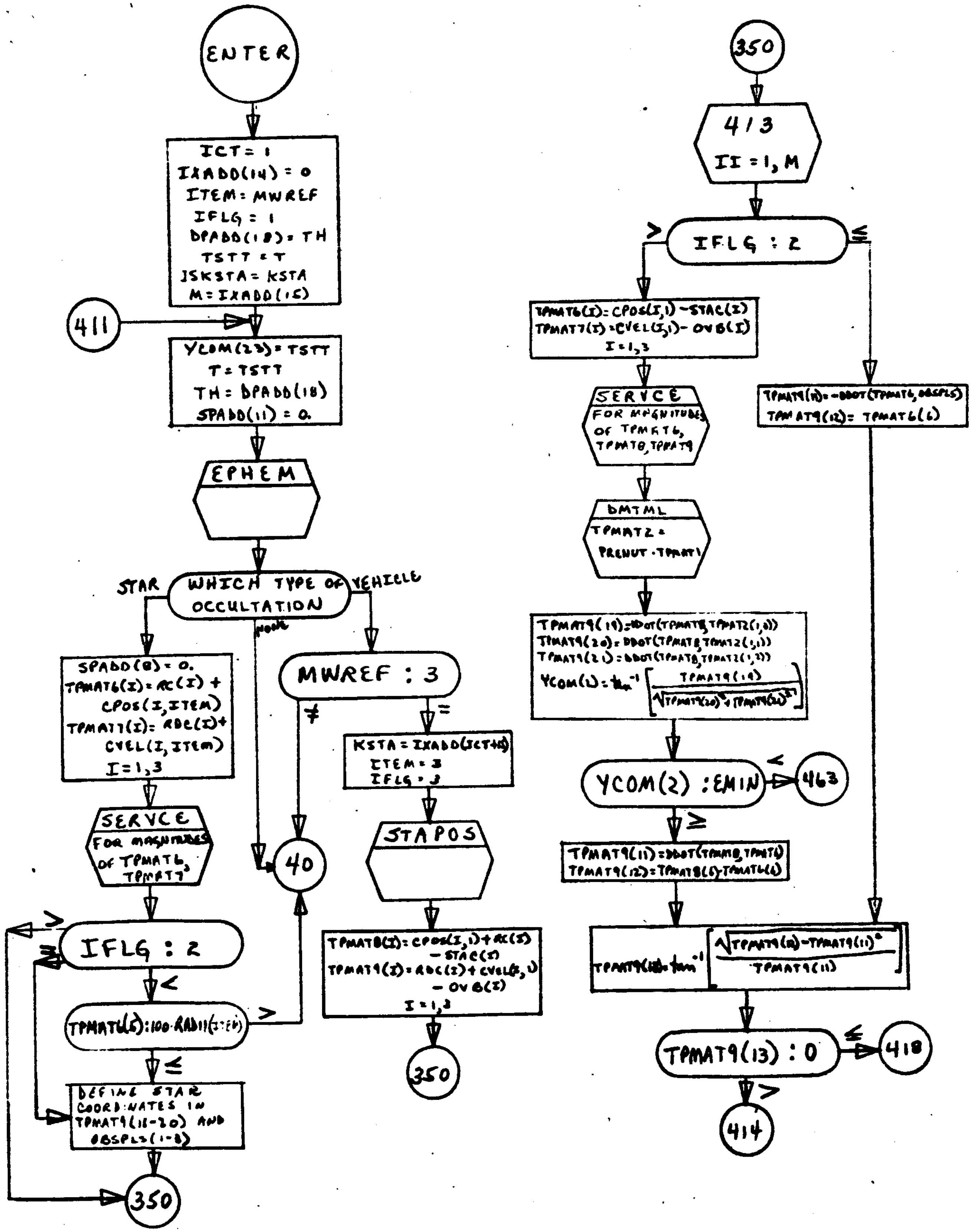
ISKSTA - saved station number

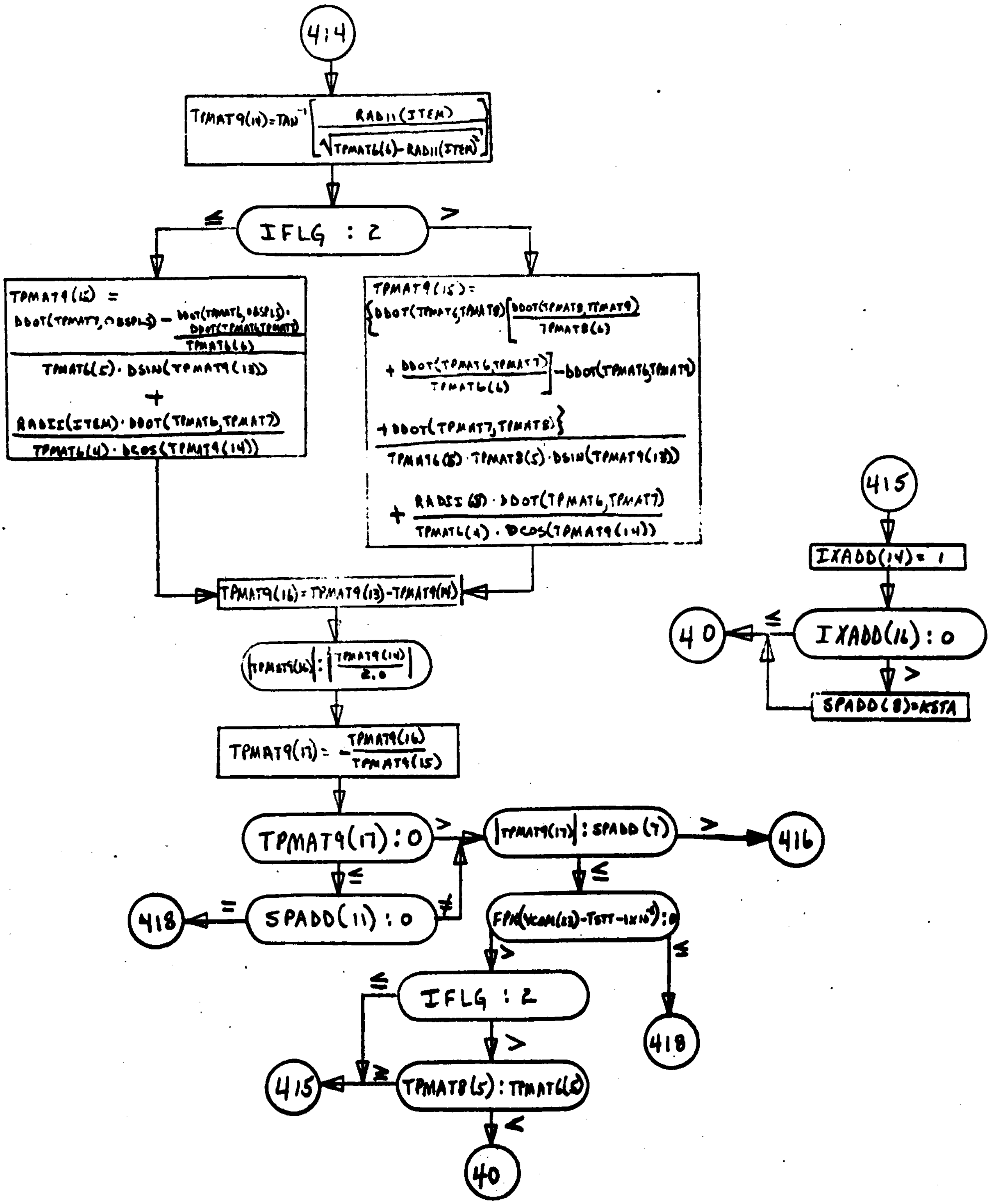
ITEM - saved value of reference body

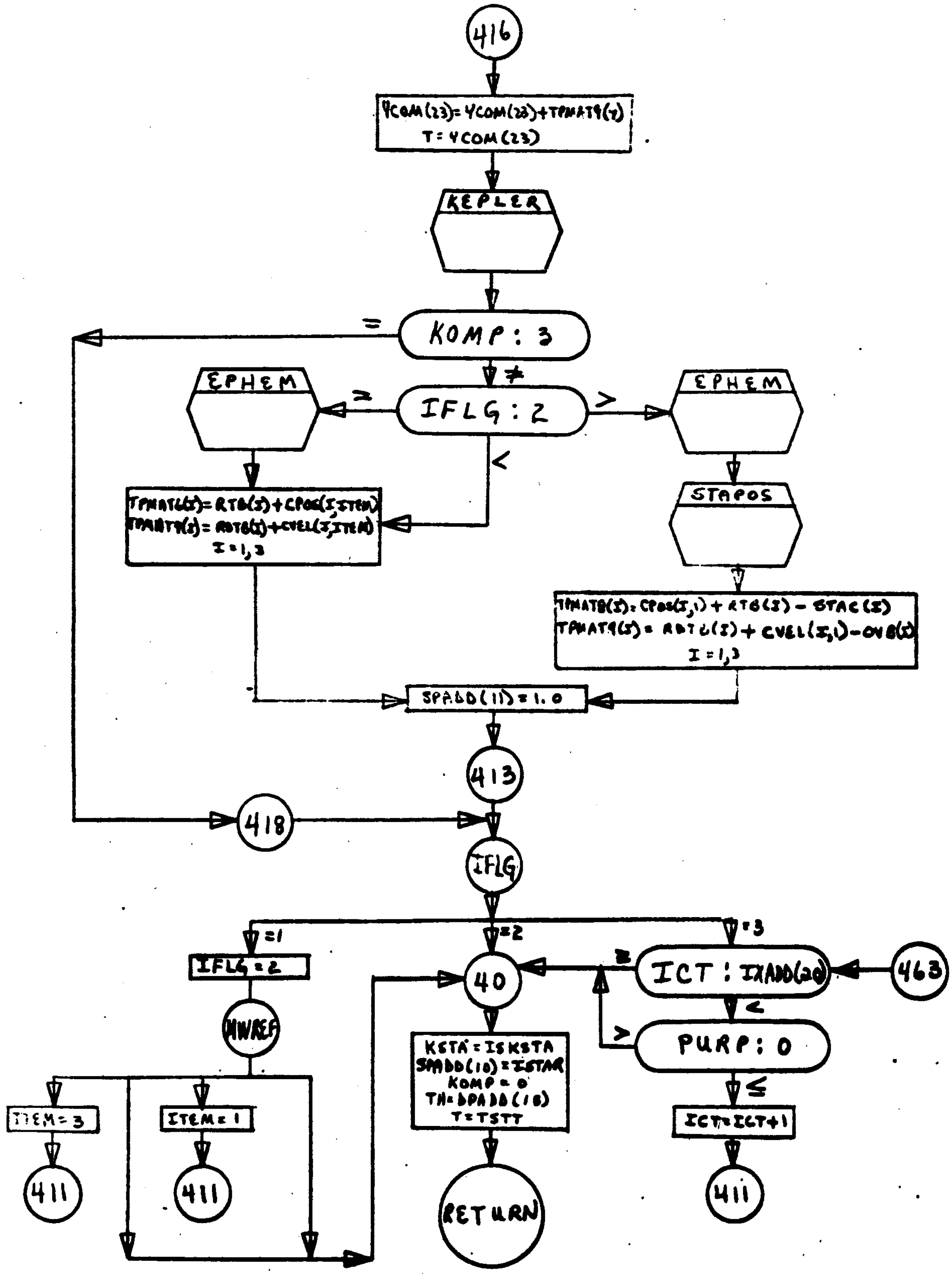
38.6 Equations Used

See Ref. 1, Section 6.2.

38.7 FLOW DIAGRAM - STACUL




414
TPMAT9(14)=TAN⁻¹[RADII(ITEM) / √(TPMAT6(6)-RADII(ITEM)²)]
IFLG : 2
TPMAT9(15) =
TPMAT6(5)·DSIN(TPMAT9(13))
RADII(ITEM)·DDOT(TPMAT6,TPMAT7)
TPMAT6(4)·DCOS(TPMAT9(14))
TPMAT9(15)=
TPMAT8(6)
TPMAT6(6)
+DDOT(TPMAT7,TPMAT8)
TPMAT6(5)·TPMAT8(5)·DSIN(TPMAT9(13))
TPMAT6(4)·DCOS(TPMAT9(14))
TPMAT9(16)=TPMAT9(13)-TPMAT9(14)
TPMAT9(17)= - TPMAT9(16) / TPMAT9(15)
TPMAT9(17):0
SPADD(11):0
418
416
IFLG : 2
TPMAT8(5):TPMAT6(5)
415
40
418
415
IXADD(14)=1
IXADD(16):0
SPADD(8)=KSTA
40


416
YCOM(23)=YCOM(23)+TPMAT9(7)
T=YCOM(23)
KEPLER
KOMP : 3
=
≠
EPHEM
IFLG : 2
=
>
<
EPHEM
TPMAT8(I)=RTB(I)+CPOS(I,ITEM)
TPMAT9(I)=RDTB(I)+CVEL(I,ITEM)
I=1,3
STAPOS
TPMAT8(I)=CPOS(I,1)+RTB(I)-STAC(I)
TPMAT9(I)=RDTB(I)+CVEL(I,1)-OVB(I)
I=1,3
SPADD(11)=1.0
413
418
IFLG
=1
=2
=3
IFLG=2
NWREF
ITEM=3
ITEM=1
411
411
40
ICT : IXADD(20)
463
=
<
>
PURP : 0
≤
KSTA=ISKSTA
SPADD(10)=ISTAR
KOMP=0
TH=DPADD(10)
T=TSTT
ICT=ICT+1
RETURN
411

39. Subroutine STAPOS

39.1 Purpose

This subroutine computes the station position and velocity vectors.

39.2 Method

The subroutine computes the location and velocity of stations on the surface of the earth in inertial coordinates.

39.3 Program References

39.3.1 STAPOS is called by:

A - OBSERA
B1 - OBSRB1

39.3.2 STAPOS calls:

DMTML, DOMOD, NUTPRE

39.4 I/O Data

39.4.1 Inputs from COMMON

EPSSQ, GAM, IRENUT, STAHT, STALN, STALT, STACR
KSTA, MPLUS1, MPLUS2, MPLUS3, NCDST, ONE

39.4.2 Outputs to COMMON

GHA, STAC

39.4.3 Other Inputs

None

39.4.4 Other Outputs

None

39.5 Symbols Used

39.5.1 COMMON Symbols

TPMAT, TPMAT1, TPMAT4

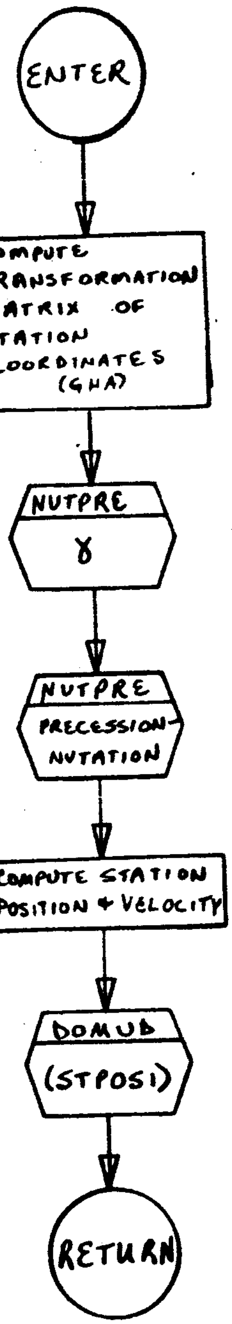
39.5.2 Other Symbols

STPOS1 - BCD word = STAPOS

39.6 Equations Used

See Ref. 1, Section 6.

39.7 FLOW DIAGRAM - STAPOS



40. Subroutine TIMNGA

40.1 Purpose

This subroutine determines the time at which the program is to compute the observation and printing for the A mode.

40.2 Method

Logic is set up for establishing an array of times of interest from which the earliest time is selected. Flags are set when the time selected is TMAX and when a time is repeated.

40.3 Program References

TIMNGA is called by:

MAINA

40.4 I/O Data

40.4.1 Inputs from COMMON

DELTP, PFPAR, RRATE, T, TMAX
ID, IPFT, IPS, KM, KSTA, MAXSTA, MDE, MINUS1, MINUS2, MPLUS1, MPLUS2, NA, NPFSET, NUT, PFON, TDELAY

40.4.2 Outputs to COMMON

TD, TSCAN, TSUBN
FPK, IRT, IXADD(5), KM, KSTA, MFLAG

40.4.3 Other Inputs

None

40.4.4 Other Outputs

None

40.5 Symbols Used other than COMMON

PREVTN - last time processed

TX - time 0 or TMAX, depending on direction of integration

TY - assigned the time opposed to TX

FPIP - floating point IPS, 0 or 1 depending on direction of integration

FPN - floating point NUT, 0 or 1

IST1 - flag for selecting powered flight parameters

IST2 - flag for selecting powered flight parameters

K - indicates direction of integration

VNA - floating point NA element

40.6 Equations Used

K = (2 IPS - 1) (2 ID - 1)

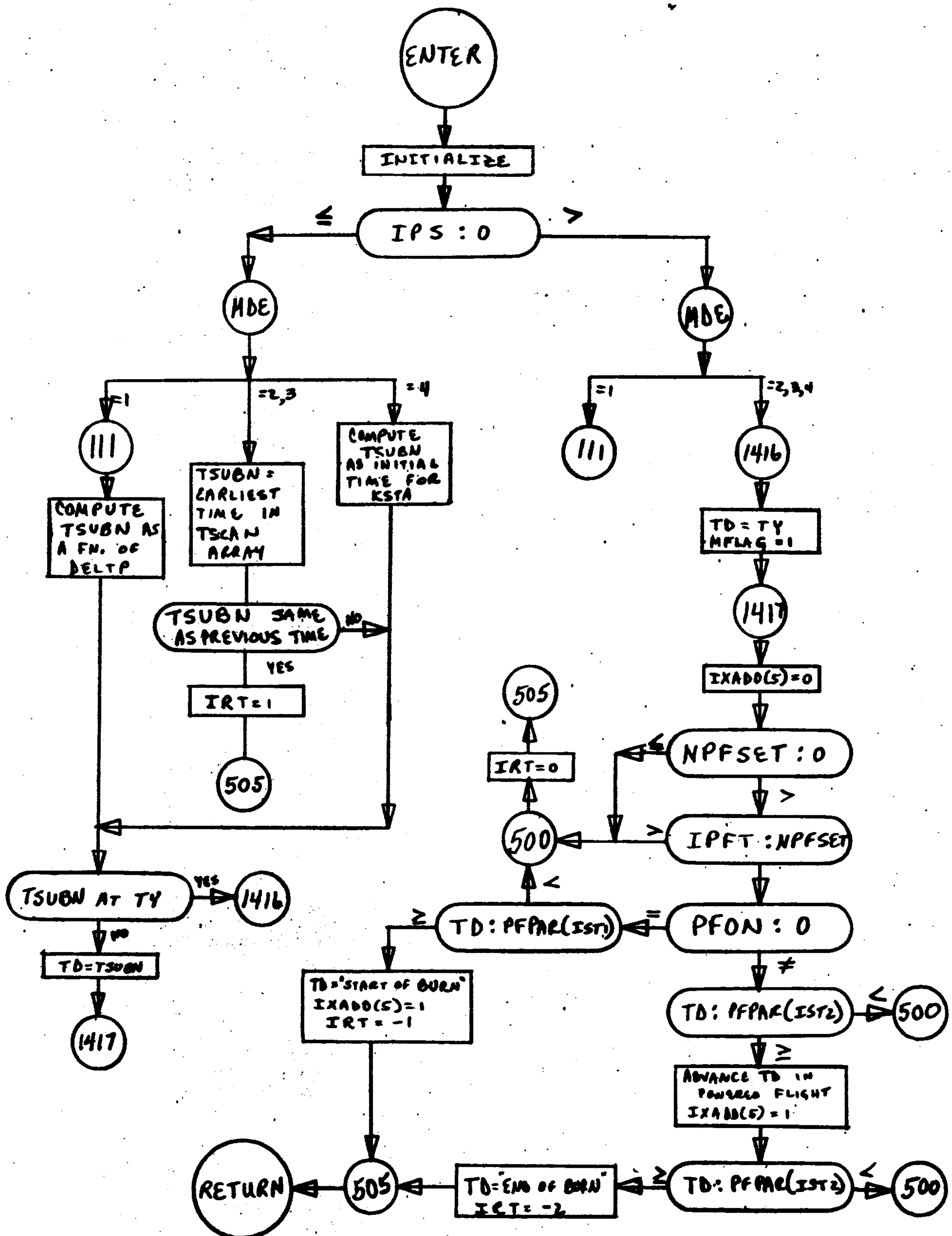
ID is 0 if TMAX > 0

ID is +1 if TMAX < 0

IPS is 0 if integration is to proceed away from T_0

IPS is 1 if integration is to proceed toward T_0

40.7 FLOW DIAGRAM - TIMNGA



41. Subroutine XFORM

41.1 Purpose

This subroutine accepts input information concerning the vehicle's initial conditions, in any one of several coordinate systems and units, then converts them to the internal units. In addition, if desired, the coordinates can be transformed into the base date system transformation through precession, nutation and/or libration.

41.2 Method

See "Equations Used"

41.3 Program References

41.3.1 XFORM is called by:

A - INPUTA

B1 - INPTB1

41.3.2 XFORM calls:

DMTML, DOMUD

41.4 I/O Data

41.4.1 Inputs from COMMON

CRAD, DIN, EPSSQ, SEC, T, TB, TWOPI
HMIN, HRS, M6, MPLUS1, MPLUS3, ONE,SIXTY, SUMCOM, THREE, TWO

41.4.2 Outputs to COMMON

CT, D, DT, E, EQ, GAM, GAMM, GHA, PRENUT, PROPNL, PSI, RCIN, RDCIN, TPMAT9 (1-6), TTMAT1, TTMAT3, WE, XC, XM, XO
IXADD (6-9), KLIBR, KSNAP, MRREF

41.4.3 Other Inputs

KLM, KLM1, KLM2, KLM3 - See Ref. 2, Input Section 2

41.4.4 Other Outputs

None

41.5 Symbols Used

41.5.1 COMMON Symbols

TPMAT, TPMAT1, TPMAT4, TPMAT5, TPMAT6, TPMAT7

41.5.2 Other Symbols

XNUT1 - BCD word = XFORM

41.5.2.1 For computing expressions for nutation and libration

GP, XL
G(21), S (21), X2C, X2GP, X2L, X3C

See write-up for NUTPRE (30.5)

41.5.2.2 For computing precession, nutation

CONV, TPR, TZP - See NUTPRE (30.5)

41.5.2 For computing libration

AIOTA, CDEL, CEE, CI, CO, COSP, CV, DEL, DOSI, EE, G, GW2, G2W2, GP, OSP, SDEL, SEE, SG, SI, SIR, SO, SO2, SOSP, SV, V, W, W2

AU, R

See write-up for CMNOBP (7.5)

41.5.2.4 For computing γ matrix

$\left.\begin{array}{l}\text{X3}\\ \text{DELAPH}\end{array}\right\}$ - See NUTPRE (30.5)

41.5.2.5 Transformation Portion

SCAL (3, 7) - table of conversion factors

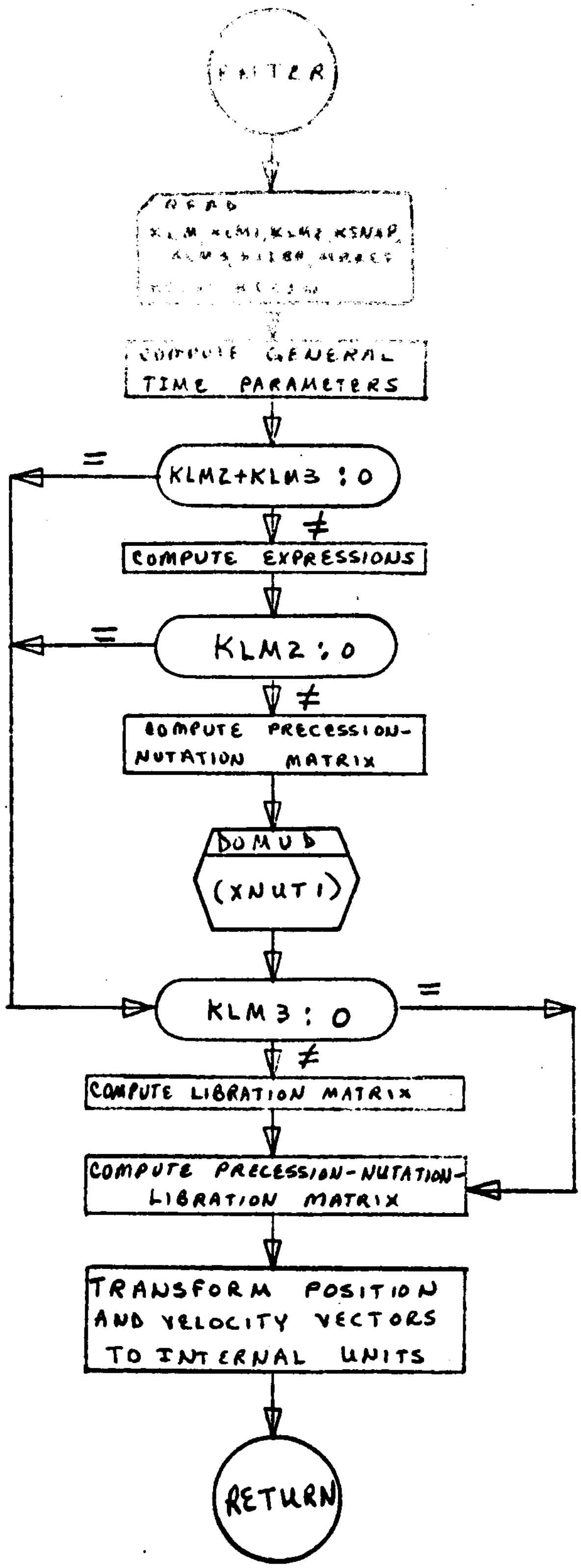
X, X3, X4, X6 - scale factors

DI - integer value of D

IGFLG, KLMM, KMOON - flag words

41.6 Equations Used

See Ref. 1, Appendix A


COMPUTE GENERAL
TIME PARAMETERS
=
KLM2+KLM3 : 0
≠
COMPUTE EXPRESSIONS
=
KLM2 : 0
≠
COMPUTE PRECESSION-
NUTATION MATRIX
DOMUD
(XNUTI)
KLM3 : 0
=
≠
COMPUTE LIBRATION MATRIX
COMPUTE PRECESSION-NUTATION-
LIBRATION MATRIX
TRANSFORM POSITION
AND VELOCITY VECTORS
TO INTERNAL UNITS
RETURN

42. Subroutine BAYSB1

42.1 Purpose

This subroutine provides the major logic for solution of the orbit determination problem by the use of Bayes estimation methods.

42.2 Method

This subroutine utilizes information from the satellite ephemeris tape and from its own internal subroutines. In the Bayes method, a Newton-Raphson iteration technique is employed until certain input convergence criteria are met. Upon convergence, the estimates of the input states and their uncertainties are updated from the initial time to the final time with intermediate prints, if needed. See Section 2 of this manual for a complete description of the interplay among the MAINB1, BAYSB1, EXECB1 and SUMARY routines.

42.3 Program References

42.3.1 BAYSB1 is called by:

MAINB1

42.3.2 BAYSB1 calls:

DALFA, DDOT, DMTML, DOMUD, FIX, MAT1NV, PASMB1, PB1A, PRNTB1, SBSRB1, SERVCE, SNOBS, SNPTL, STLSB1, SYMMAT

42.4 I/O Data

42.4.1 Inputs from COMMON

DELY, RC, RDC, T, TIN, TMAX

AMUD, C3TAB, DATTYP, FDOWN, FUP, IRDATA, ISUMRY, LSFLAG, M6, MBATCH, MPLUS1, MPLUS2, MPLUS3, MPLUS4, MWREF, MXPASS, ONE, PAST, PSPACE, REJCT1

42.4.2 Outputs to COMMON

CPOS, QSAVE, RC, RDC, STAT, YOBS
AMUD, AREJ, DATTYP, F1, F2, ICOUNT, IPLNT, JFLAG, KTAB, LSFLAG, NPASS, NUMDAT, SPADD (8), SPADD (10)

42.4.3 Other Inputs

42.4.3.1 Preconvergence Mode - LSFLAG=0

42.4.3.1.1 First record of nominal tape - logical tape 11.

a) ((STAT (I, J), J = 1, 6), I = 1, 3)

b) ((STAT (I, J), J = 1, 6), I = 4, 6)

Q^{-1}

42.4.3.1.2 Complete data set - two or more sets.

a) ICOUNT, T, RC, RDC, IPLNT, TKRAW, LTEMP, DATA, LTEMP1, MWREF, (CPOS (I, IPLNT), I = 1, 6)

b) ((ALAM1 (I, J), J = 1, 6), I = 1, 2), (CVEL (I, IPLNT), I = 1, 6)

c) ((ALAM1 (I, J), J = 1, 6), I = 3, 6)

where ALAM1 is state transition matrix and others as per COMMON descriptions

42.4.3.2 Post Convergence Mode - LSFLAG = 1

42.4.3.2.1 First record of nominal tape - logical tape 11.

Same as 42.4.3.1.1 - Q matrix

42.4.3.2.2 Truncated data set - two or more sets

a) T, RC, RDC, MWREF, ((ALAM1 (I, J), J = 1, 6), I = 1, 2)

b) ((ALAM1 (I, J), J = 1, 6), I = 3, 6)

42.4.4 Other Outputs

42.4.4.1 Preconvergence Mode - LSFLAG = 0

Same as 42.4.3.1 with the exception that STAT array is written where ALAM1 is read in.

42.4.4.2 Rejection information - BCD

II, BMAT (II, 1), YCOM (II), DELY (N)

where II is the index for the observation type

BMAT (II, 1) - observed values of observation

YCOM (II) - computed value of observation

DELY (N) - residual

42.4.4.3 Summary information - logical tape 10

T, KSTA, ICOUNT, (BMAT (I, 2), I = 1, 25), (BMAT (I, 1), I = 1, 25), AREJ

42.4.4.4 Convergence information

"Convergence has failed in (NPASS) passes"

"Convergence not attained"

"Convergence has occurred"

42.5 Symbols Used

42.5.1 COMMON Symbols

ALAM1, ATMAT, DELALP, EBAR, SAVEL1, SMAT
BMAT, KPOINT, TEMP (1)

42.5.3 Other Symbols

RCPRI (6) - saved initial position vector

RDCPRI (6) - saved initial velocity vector

TMMP - end-of-batch criterion; dummy read-in

BAYES1, BAYES2, BAYES3, BAYES4 - BCD words = (same variable name)
—used for error conditions
II - temporary storage
IRTEMP (4) - unpacked LTEMP1
K - temporary storage
KTEMP - argument in calling FIX

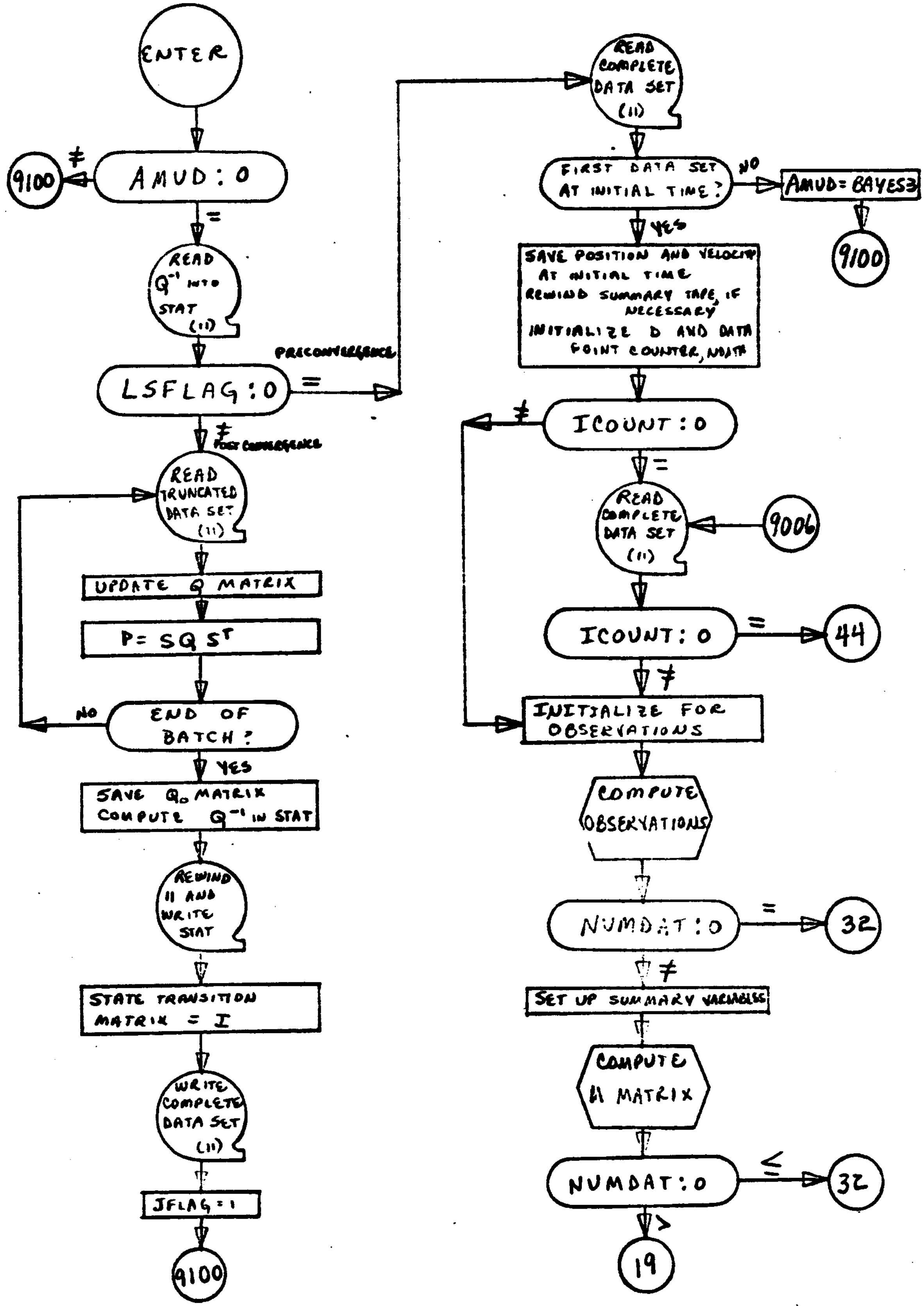
LL - index

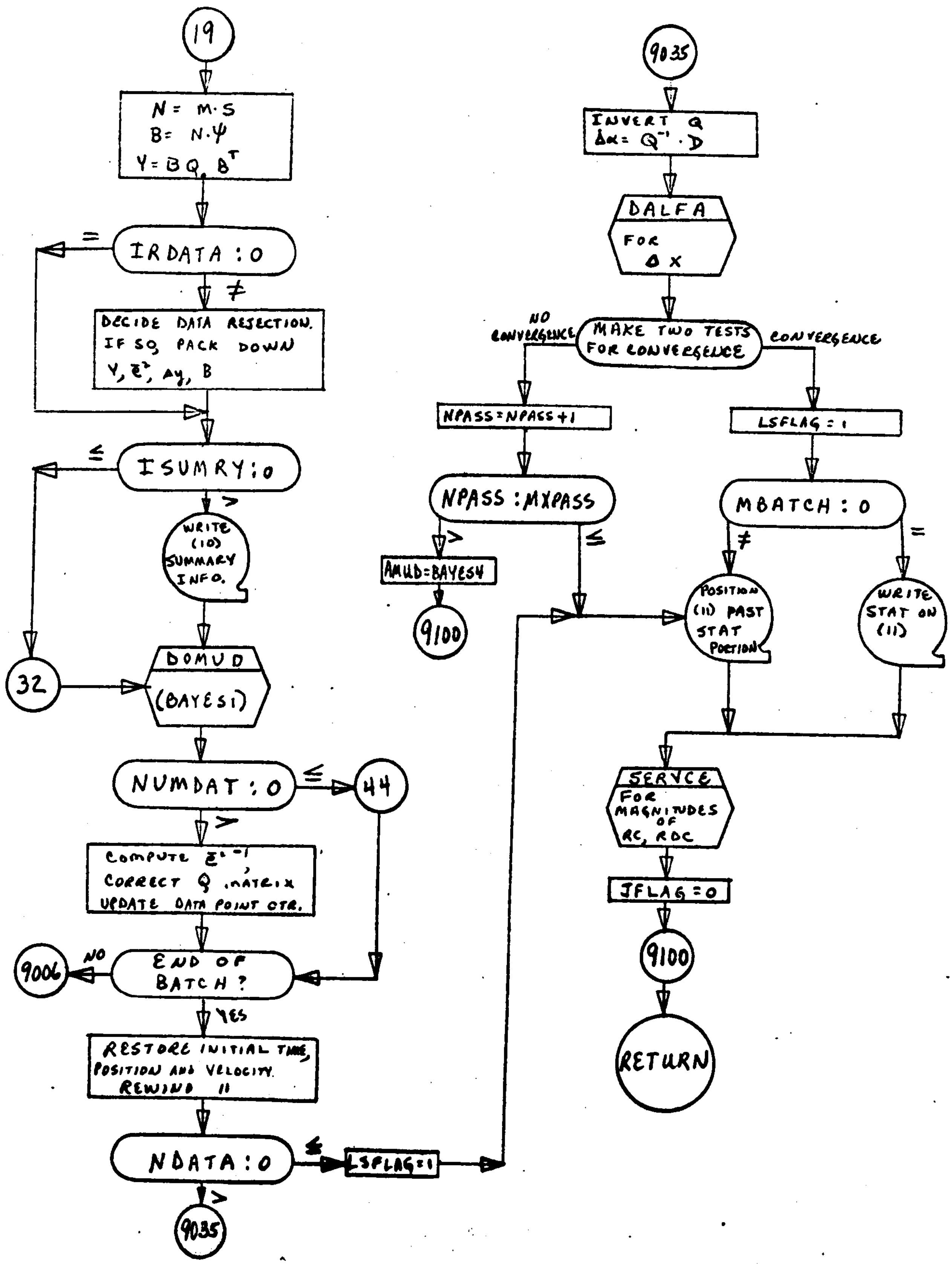
NDATA - number of good data points in a batch

NUMDTT - saved NUMDAT for packing matrices

42.6 Equations Used

See Ref. 1, Section 5.3


ENTER
AMUD : 0
9100
READ Q^{-1} INTO STAT (11)
LSFLAG : 0
PRECONVERGENCE
POST CONVERGENCE
READ TRUNCATED DATA SET (11)
UPDATE Q MATRIX
P= SQ S^T
END OF BATCH?
NO
YES
SAVE Q_0 MATRIX COMPUTE Q^{-1} IN STAT
REWIND 11 AND WRITE STAT
STATE TRANSITION MATRIX = I
WRITE COMPLETE DATA SET (11)
JFLAG = 1
9100
READ COMPLETE DATA SET (11)
FIRST DATA SET AT INITIAL TIME?
AMUD = BAYES3
9100
SAVE POSITION AND VELOCITY AT INITIAL TIME
REWIND SUMMARY TAPE, IF NECESSARY
INITIALIZE D AND DATA POINT COUNTER, NDATA
ICOUNT : 0
READ COMPLETE DATA SET (11)
9006
ICOUNT : 0
44
INITIALIZE FOR OBSERVATIONS
COMPUTE OBSERVATIONS
NUMDAT : 0
32
SET UP SUMMARY VARIABLES
COMPUTE H MATRIX
NUMDAT : 0
32
19


19
N = M·S
B = N·ψ
Y = BQ, B^T
IRDATA : 0
=
≠
DECIDE DATA REJECTION. IF SO, PACK DOWN Y, ε², Ay, B
ISUMRY : 0
≤
>
WRITE (10) SUMMARY INFO.
32
DOMUD
(BAYES1)
NUMDAT : 0
≤
44
>
COMPUTE ε²⁻¹, CORRECT Q MATRIX UPDATE DATA POINT CTR.
NO
9006
END OF BATCH ?
YES
RESTORE INITIAL TIME, POSITION AND VELOCITY. REWIND 11
NDATA : 0
≤
LSFLAG=1
>
9035
9035
INVERT Q
Δα = Q⁻¹·D
DALFA
FOR Δx
NO CONVERGENCE
MAKE TWO TESTS FOR CONVERGENCE
CONVERGENCE
NPASS=NPASS+1
LSFLAG = 1
NPASS : MXPASS
>
≤
AMUD=BAYES4
9100
MBATCH : 0
≠
=
POSITION (11) PAST STAT PORTION
WRITE STAT ON (11)
SERVCE
FOR MAGNITUDES OF RC, RDC
JFLAG = 0
9100
RETURN

43. Subroutine DALFA

43.1 Purpose

This subroutine transforms the variations in the α parameters (DELALP) to variations in the state variables (DELX).

43.2 The finite rotation method is used.

43.3 Program References

43.3.1 DALFA is called by:

BAYSB1, STATB1

43.3.2 DALFA calls:

DDOT, DOMUD, SERVCE

43.4 I/O Data

43.4.1 Inputs from COMMON

DELALP, HMU, RA, RC, RDC
MPLUS1, MPLUS2, ONE, TWO

43.4.2 Outputs to COMMON

DELX, RC, RDC

43.4.3 Other Inputs or Outputs

None

43.5 Other Symbols Used

None

43.6 Equations Used

LET $\bar{R}$ AND $\dot{\bar{R}}$ BE INPUT QUANTITIES.

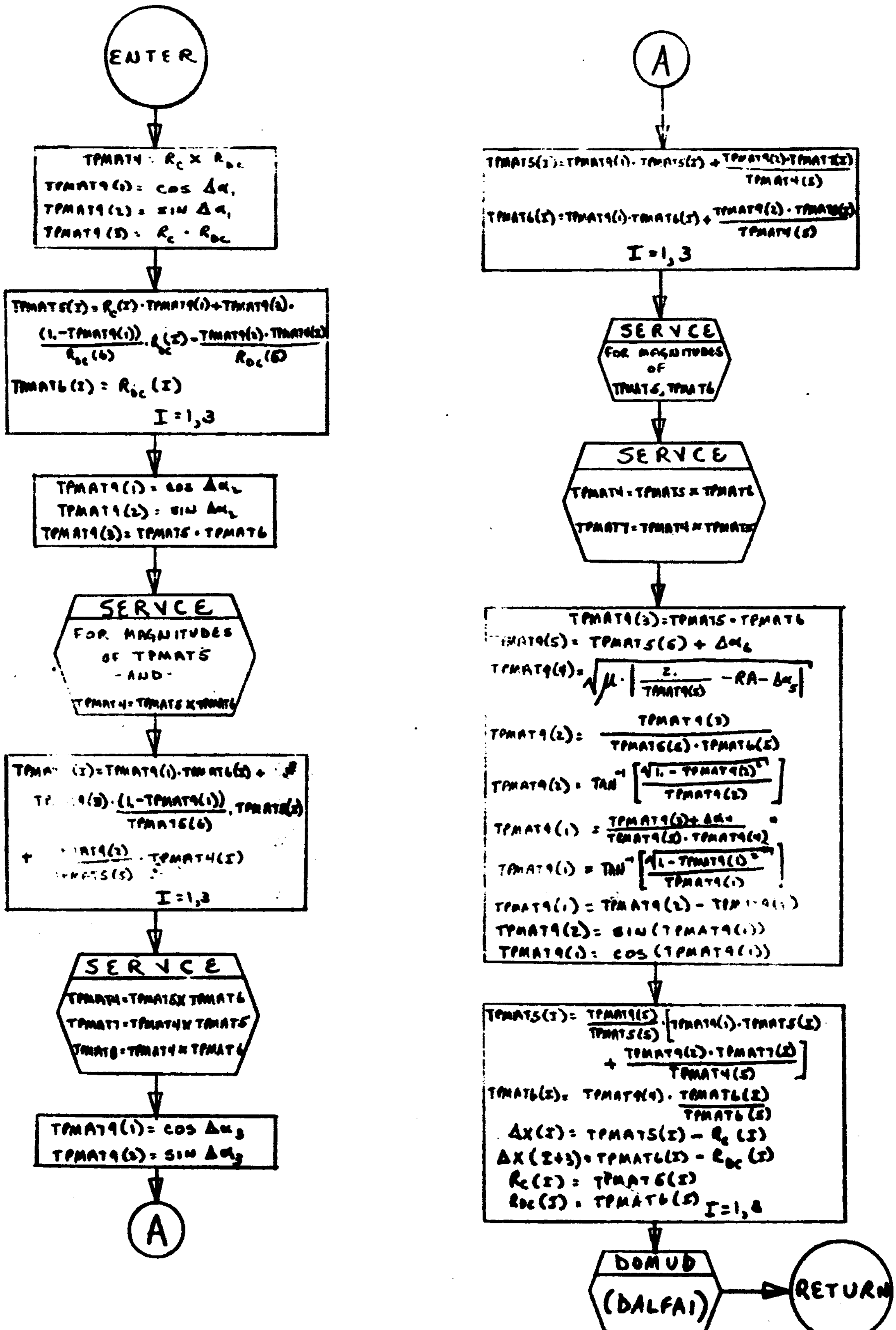
1. $\bar{H}_1 = \bar{R} \times \dot{\bar{R}}$
2. $D_1 = \bar{R} \cdot \dot{\bar{R}}$
3. $\bar{R}_1 = \bar{R}\cos(\Delta\alpha_1) + \frac{D_1}{V^2}\left[1 - \cos(\Delta\alpha_1)\right]\dot{\bar{R}} - \frac{\bar{H}_1}{V}\sin(\Delta\alpha_1)$
4. $\bar{H}_2 = \bar{R}_1 \times \dot{\bar{R}}$
5. $D_2 = \bar{R}_1 \cdot \dot{\bar{R}}$
6. $\dot{\bar{R}}_1 = \dot{\bar{R}}\cos(\Delta\alpha_2) + \frac{D_2}{R_1^2}\left[1 - \cos(\Delta\alpha_2)\right]\bar{R}_1 + \frac{\bar{H}_2}{R_1}\sin(\Delta\alpha_2)$
7. $\bar{H}_3 = \bar{R}_1 \times \dot{\bar{R}}_1$
8. $\bar{H}_1' = \bar{H}_3 \times \bar{R}_1$
9. $\bar{H}_1'' = \bar{H}_3 \times \dot{\bar{R}}_1$
10. $\bar{R}_2 = \bar{R}_1\cos(\Delta\alpha_3) + \frac{\bar{H}_1'}{H_3}\sin(\Delta\alpha_3)$
11. $\dot{\bar{R}}_2 = \dot{\bar{R}}_1\cos(\Delta\alpha_3) + \frac{\bar{H}_1''}{H_3}\sin(\Delta\alpha_3)$
12. $D_3 = \bar{R}_2 \cdot \dot{\bar{R}}_2$
13. $\bar{H}_4 = \bar{R}_2 \times \dot{\bar{R}}_2$
14. $\bar{H}_2' = \bar{H}_4 \times \bar{R}_2$
15. $A = \dfrac{1}{\frac{2}{R_2} - \frac{V_2^2}{\mu}}$
16. $(AP) = \dfrac{A}{1 + A \cdot \Delta\alpha_5}$
17. $R' = R_2 + \Delta\alpha_6$
18. $V' = \sqrt{\mu \left/ \left(\frac{2}{R'} - \frac{1}{(AP)}\right)\right.}$
19. $T = \dfrac{D_3}{R_2 V_2}$
20. $L = \sqrt{1 - T^2}$
21. $\Gamma = \tan^{-1}\left(\frac{L}{T}\right)$

    IF Γ IS NEGATIVE,

    $\Gamma' = \Gamma + \pi$
22. $T_1 = \dfrac{D_3 + \Delta\alpha_4}{R'V'}$
23. $L_1 = \sqrt{1 - T_1^2}$
24. $\Gamma_1' = \tan^{-1}\left(\frac{L_1}{T_1}\right)$

    IF Γ_1' IS NEGATIVE,

    $\Gamma_1'' = \Gamma_1' + \pi$
25. $\Gamma_2 = \Gamma' - \Gamma_1'$
26. $\bar{R}_3 = \frac{R'}{R_2}\left\{\bar{R}_2\cos\Gamma_2 + \frac{\bar{H}_2'}{H_4}\sin\Gamma_3\right\}$
27. $\dot{\bar{R}}_3 = \frac{V'}{V_2}\dot{\bar{R}}_2$
28. $\Delta\bar{R} = (\bar{R}_3 - \bar{R})$
29. $\Delta\dot{\bar{R}} = (\dot{\bar{R}}_3 - \dot{\bar{R}})$
30. $\bar{R} = \bar{R}_3$
31. $\dot{\bar{R}} = \dot{\bar{R}}_3$


ENTER
TPMAT4 = R_c × R_bc
TPMAT9(1) = cos Δα_1
TPMAT9(2) = sin Δα_1
TPMAT9(3) = R_c · R_bc
TPMAT6(I) = R_bc(I)
I = 1,3
TPMAT9(1) = cos Δα_2
TPMAT9(2) = sin Δα_2
TPMAT9(3) = TPMAT5 · TPMAT6
SERVICE
FOR MAGNITUDES OF TPMAT5
-AND-
I = 1,3
SERVICE
TPMAT9(1) = cos Δα_3
TPMAT9(2) = sin Δα_3
A
A
I = 1,3
SERVICE
FOR MAGNITUDES OF
SERVICE
TPMAT9(3) = TPMAT5 · TPMAT6
TPMAT9(2) = sin (TPMAT9(1))
TPMAT9(1) = cos (TPMAT9(1))
ΔX(I) = TPMAT5(I) − R_c(I)
ΔX(I+3) = TPMAT6(I) − R_bc(I)
R_c(I) = TPMAT5(I)
R_bc(I) = TPMAT6(I)
DOMUD
(DALFAI)
RETURN

44. EXECB1

44.1 Purpose

This routine is the executive program for the B1 mode.

44.2 Method

This routine calls the input routine, the B1 main routine and the summary routine.

44.3 Program References

EXECB1 calls:

INPTB1, MAINB1, SUMARY

44.4 I/O Data

44.4.1 Inputs from COMMON

AMUD, FIRST, INPERR, ISTAT, ISUMRY, KLAST, KTAB, MPLUS1, NOFT, NT

44.4.2 Outputs to COMMON

FIRST, NT

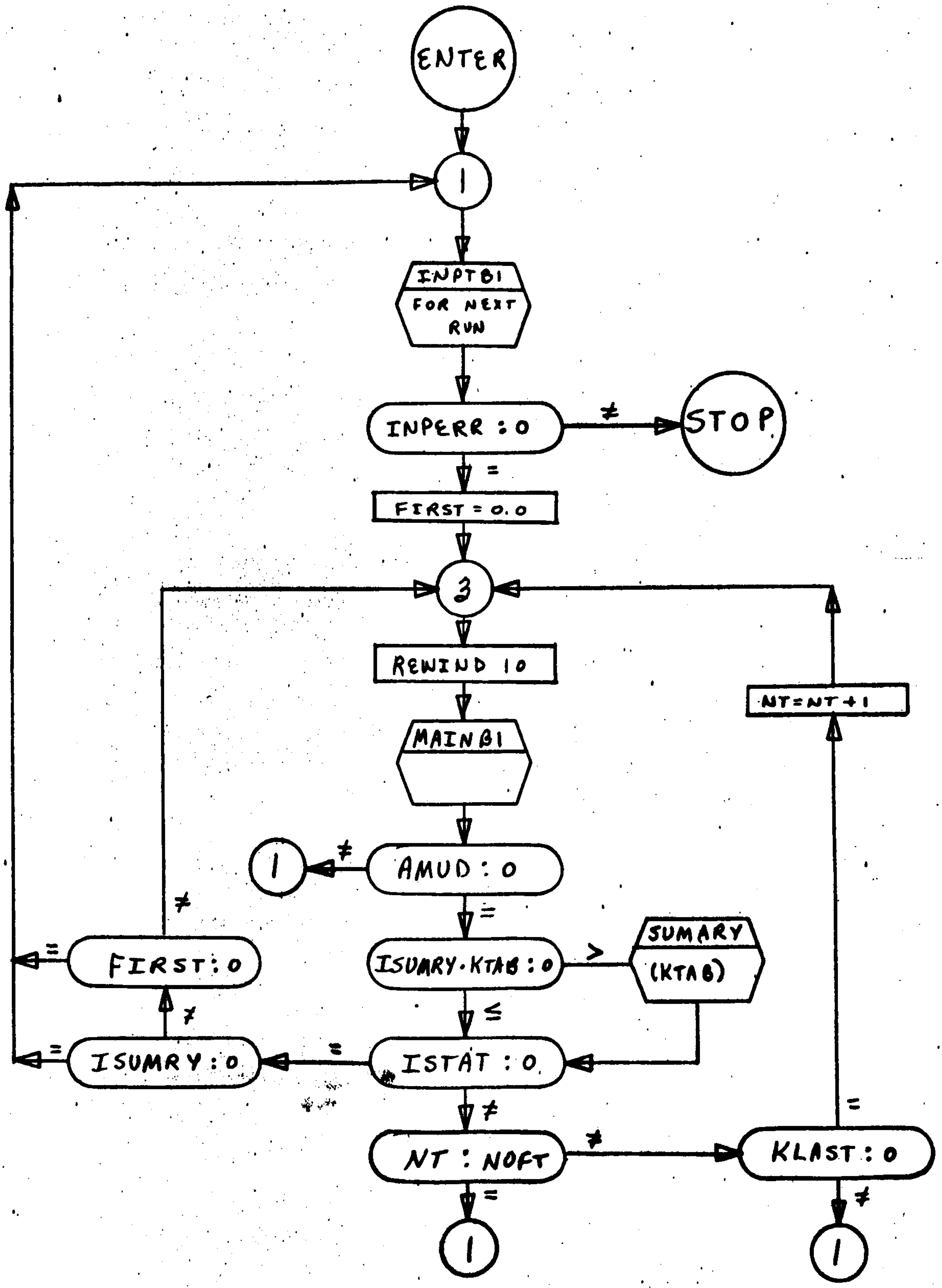
44.5 Symbols used other than COMMON

None

44.6 Equations Used

None

44.7 FLOW DIAGRAM - EXECB1



45. Function FLORNG (RMEAN, RSIGMA, IGUESS, RNGFLG)

45.1 Purpose

This subroutine generates random noise in the B1 and B2 modes for simulated data.

45.2 Method

The subroutine computes the pseudo-random number satisfying the rectangular density function in the interval (0,1) and from that generates the Gaussian pseudo-random number with a mean of $\bar{X}$ and standard deviation of σ.

The sequence is cyclic for 2^{35} numbers generated.

45.3 Program References

FLORNG is called by:

B1 - OBSRB1, ONOBS, SBSRB1, SNOBS
B2 - B2BOB, B2OBOS, B2STOB, OBBSR

45.4 I/O Data

45.4.1 Inputs

IGUESS - current value of the pseudo-random number satisfying the rectangular density function

RMEAN - statistical mean, $\bar{X}$

RSIGMA - standard deviation, σ

45.4.2 Outputs

FLORNG - the Gaussian random number

IGUESS - same as above

RNGFLG - the floating point value of IGUESS

45.5 Symbols Used

CONV - scaling factor, 2^{35}

ARG - $2\pi X_{i+1}$

K - constant used for generating rectangular density, octal .788

X(2) - the 2 pseudo-random numbers satisfying the rectangular density function

45.6 Equations Used

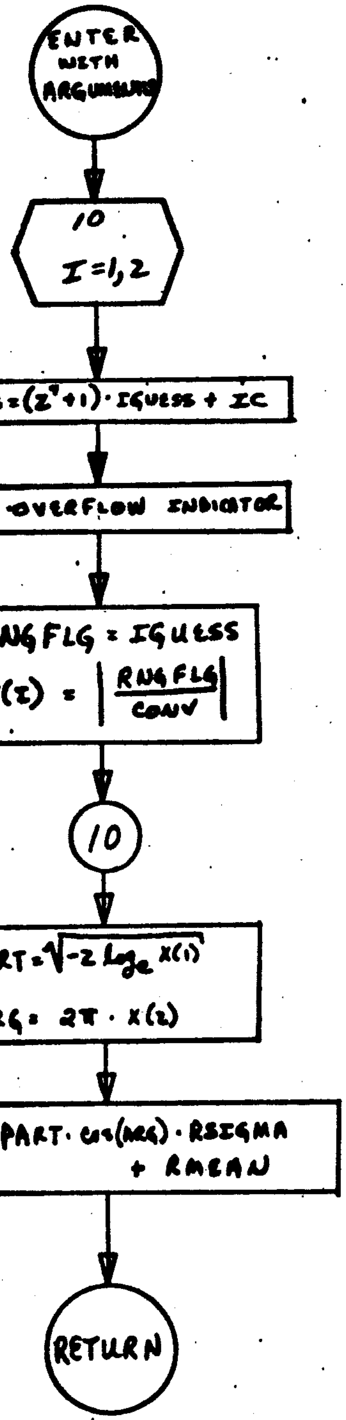
Pseudo - random numbers satisfying the rectangular density function

$$X_{i+1} = (2^7 + 1)\, X_i + .788$$

Gaussian pseudo-random number

$$\bar{X} + \sigma\, (-2 \log_e X_i)^{\frac{1}{2}} \cos 2\pi\, X_{i+1}$$

45.7 FLOW DIAGRAM - FLORNG



46. Subroutine INPTB1

46.1 Purpose

This subroutine reads in all data necessary for one run.

46.2 Method

The subroutine initializes necessary data and reads in sections desired. Depending on the input quantity KSTDRD, certain variables are either read in or set up within the program to nominal values.

46.3 Program References

46.3.1 INPTB1 is called by:

EXECB1

46.3.2 INPTB1 calls:

DDOT, DMTML, DOMUD, FIX, MATINV, PASME1, SERVCE, XFORM

46.4 I/O Data

46.4.1 For a complete listing of data deck see Ref. 2, Section 2.2

A printout is made of all input quantities.

46.4.2 In Bayes statistics, Q^{-1} is written on logical tape 11 on two records.

((STAT(I,J), J=1,6), I=1,3)
((STAT(I,J), J=1,6), I=4,6)

46.5 Symbols Used

DYNARR(60) - (Data)- nominal values of dynamic states.
SCAL(3,7) - (Data) - the matrix for which the array SCALE is chosen, depending on IUNIT.
TZ - time from start of launch day

ALPHA(3,7) - (Data) - Matrix from which the array PVALPH is chosen, depending on IUNIT.
CDN(40) - (Data) - Standard coefficient of drag table.from which CDT is set
DAYN - number of days from Jan. 1, 1960 to launch year
DTSUP - Print suppression portion of print interval (TAU)
IGGSD - initial guess for random number generator

IPR(8) - (Data) - array of alphameric titles
ITITLE(12) - array read in for title of run
IN - index for IPR array
NN - index of first STAOR variable to be read in
NN2 - index of last STAOR variable to be read in
PASTD - data word for setting PAST
PSPACD - data word for setting PSPACE
RECT1 - BCD word = RECT1
XMACHN(40)-(Data)- standard Mach number tables from which XMACH is set up

46.6 Equations Used

When P matrix read in, transformation to Q matrix is as follows:

$$Q = S^{-1}P(S^{-1})^T$$

46.7 Flow Diagram

See INPUTA(26.7)

47. Subroutine MAINB1

47.1 Purpose

The purpose of the MAINB1 program is to control the program through its major phases. The principal functions of this subroutine are:

- Read the data tape and select points to be processed
- Provide logical controls for the Bayes and the Minimum Variance Statistics sub-programs
- Provide logical controls for the Encke and The Cowell Integration sub-programs
- Time correct data when requested by the user

47.2 Method

The routine has been divided into 7 principal sub-sections. These sub-sections are illustrated in the general flow diagram which follows. Their names and functions are:

47.2.1 Minimum Variance Initialization

Provides initial values for many variables common to the minimum variance statistics program. Initialization of these variables cannot be made in INPUT because of the ability of the program to iterate through the data without returning to the INPUT routine.

47.2.2 Bayes Initialization

Provides the controls for starting the Bayes process upon first entry from EXECB1 as well as controlling the iteration process when convergence does not occur on the first pass through the data. It also controls a preliminary mode which may have usefulness in cases where the *a priori* initial conditions are poor.

47.2.3 Timing Control Section

Provides the controls for selection of "times of interest" (program symbol TD). These "times" are discrete values to which the program is always referenced. Examples of these "times of interest" are:

- Initial Time
- Final Time
- Data Point Times
- Print Times
- Burn Start and Burn Completion Times

Included in this section is the "RECORD" sub-section whose purpose is to read the data tape, to select data points of interest to the user (based on inputted information), to resolve ambiguities in Range and Range Rate data from certain systems, and to convert certain types of data to units acceptable to the program.

47.2.4 Integration Control Section

Provides proper calls to the Encke or Cowell integrator and, when returning from these integrators, provides the flow of the subsequent operations depending upon the reason for returning from the integrators.

Encke integration returns when:

a. A rectification is indicated

(MAINB1 tests the rectification criteria indicator (KOMP). If the reason for rectification is because of a change of reference planet, the integration control section transforms the state transition matrix into values appropriate to the new reference body).

b. T = TD, TD being the present "time of interest".

Cowell Integration returns when:

a. T = TD, as above for Encke

b. Reference body change is indicated

Although the Cowell method does not require rectification as in the Encke method, the state transition matrix employed in either case is the two-body STM. Therefore, a two-body subroutine (KEPLER) is employed. Since the accuracy of this STM is proportional to the closeness of the two body trajectory to the N-body, tests for the deviation between the two are made at appropriate intervals. When this test indicates a significant deviation has developed, the two-body model and the STM are "updated" by the rectification process.)

47.2.5 Minimum Variance Main Control Section

This section controls calls to the minimum variance statistics subroutine "STATB1" and to the trajectory print routine. It sets up special flags depending upon the reason for calling STATB1.

47.2.6 Minimum Variance End Control Section

This section provides the logic for terminal procedures when required.

47.2.7 Bayes Main Control Section

This section has two main functions. First, it controls the writing of data on a scratch tape. These data include the satellite ephemeris, observation data, the state transition matrix, and certain planet ephemeris information. A second function is to properly terminate the Bayes procedure both when convergence has and has not been achieved

47.3 Program References

47.3.1 MAINB1 is called by:

EXECB1

47.3.2 MAINB1 calls:

BAYSB1, CITGRA, DDOT, DMTML, EITGRA, FIX, KEPLER, NUTPRE, PASMB1, PB1A, PDUMP , PFINIT, RECT, STACUL, STATB1

47.4 I/O Data

47.4.1 Inputs from COMMON

ALAM1, COMB, CPOS, DELTP, DTK, DTL, GAMM, ORM, PFPAR, PREVTN, RC, RDC, RDI, RDTB, RI, RT1, RT2, RTB, SMAT, STALN, STALT, T, TD, TMAX, TMAX2, TPRELM, TSPAN, TSUBN, TX, TZHRS, YOBSNU
AMUD, C2TAB, C3TAB, CEPID, CLUE, CNT, FDOWN, FIRST, FPK, FUP, ID, IMODE, IPFT, IPS, IRT, ISTAT, ISUMRY, ITER2, KOMP, KSTA, KTC, MPLUS1, MPLUS2, MPLUS3, MPLUS4, NA, NPFSET, NUMDAT, ONE, PASF, PASS, PFLAG, SLUE, SPADD (9), SUMCOM, TDELAY, TWO, TYPE

47.4.2 Outputs to COMMON

ALAM1, DELTP, FRQ, ORM, PREVTN, RDI, RI, TD, TIN, TK, TKRAW, TL, TMAX, TMAXX, TP, TSUBM, TSUBN, TX, TY, YOBS
CLUE, CNT, DATTYP, F1, F2, FIRST, FPIP, IMODE, IMODES, IPFT, IPS, IRT, ITER2, ITERS, IXADD (16), KLAST, KOMP, KSTA, KTAB, LSFLAG, MBATCH, MFLAG, NA, NPASS, NT, NUM, NUMDAT, NUT, PASF, PASS, PFLAG, PFON, TDELAY, USETYP, VMASS

47.4.3 Other Inputs

From tape 9-binary

TKRAW, LTEMP, TEMP (1-4), LTEMP1, ICOUNT

47.4.4 Other Inputs

47.4.4.1 Least Squares - truncated binary data set on tape 11

1) T, RC, RDC, MWREF,((STAT (I, J), J = 1, 6), I = 1, 2)

2) ((STAT (I, J), J = 1, 6), I = 3, 6)

47.4.4.2 Least Squares - complete data set on tape 11

1) ICOUNT, T, RC, RDC, ICOUNT, TKRAW, LTEMP, DATA, LTEMP1, MWREF, (CPOS (I, IPLNT), I = 1, 6)

2) ((STAT (I, J), J = 1, 6), I = 1, 2), (CVEL (I, IPLNT), I = 1, 6)

3) ((STAT (I, J), J = 1, 6), I = 3, 6)

47.4.4.3 T for "START OF BURN" and "END OF BURN"

47.5 Symbols Used

47.5.1 COMMON Symbols

TPMAT4, TPMAT5, TPMT10

47.5.2 Other Symbols

DATA (4) - Temporary storage of observation from data type

FPN - Floating point value indicating whether T is at 0 or at T_{MAX}

IDUM - Number of powered flight burn period just completed

IFACTR - The integer factor used in building up the new packed indicator word during rejection testing

IFPK - + or -1, depending on direction of integration (used in burn phase)

IT - An index used for picking up the proper value in several tabular arrays

IRRDOT (4) - unpacked LTEMP1

ISCONT - saved ICOUNT

J - Temporary storage of the data type code number

KTEMP - saved KSNAP

LLL - A flag, when set non-zero, which specifies if a valid observation exists within a data set

LM - Temporary storage at the data type code number

M - An indicator derived from the unpacked LTEMP1, which, when non zero, indicates that a data point from the Goddard R/Ṙ system is to be rejected.

MFB - Indicator used to determine which time in powered flight array, PFPAR, is finish of burn

MSB - same as MFB, except indicates start of burn

NNN - an index used for picking up the proper value from a tabular array

NUMVAL (4) - unpacked NUM (KSTA)

TA - The period of the lowest range tone used in ambiguity resolution

TRT - The correct (unambiguous) round trip propagation time

XK - The bias frequency to be used with the current data set

XN - The cycle count to be used with the current data set

47.6 "RECORD" Subsection

47.6.1 Purpose

The purpose of the RECORD portion of the MAIN program is to continually provide the proper set of observation data for statistical processing.

47.6.2 Method

First, the program reads sets of observation data until the first raw time of observation which is less than or equal to current time in the program is reached. This set is then subjected to a series of tests against various criteria to determine whether some or all of the observations within a set are to be rejected. If all are rejected, the data tape is re-read until a set is obtained with one or more acceptable observations.

If the acceptable data set is within an allowable time interval of current time, and the time correction option has been specified, the raw observation time will be modified. This modified time is then used by the program to determine when the observation set is to be processed.

With data from the Goddard Range and Range Rate System, ambiguities in the observed data must be resolved.

47.6.3 Program References

The SIMPLE RECORD is itself a block of coding contained in the MAIN program.

Subroutines called are:

EPHEM , FIX, KEPLER, NUTPRE

47.6.4 I/O Data

The following variables are read from the data tape: (logical tape 9)

TKRAW - the raw time, in hours, of the data set, referenced to 0 hours, January 1, 1960.

LTEMP - A packed word, consisting of station number and observation types for the data set.

TEMP (I), I = 1, 4 - the observation values, for which at least the first must be non-zero.

LTEMP1 - A packed word, consisting of a data rejection indicator and four flags for use in time correction and ambiguity resolution.

ICOUNT - The record number of the observation set on the data tape.

47.7 Equations Used

47.7.1 Ambiguity Resolution in the Goddard $R/\dot{R}$ System

Range

The table (C1TAB) contains 3 frequencies: 8, 32 and 160 c/s. The first number in the unpacked data word LTEMP1 must be converted to pick up the proper frequency from C1TAB. The algorithm used is:

$$I = K - \mathrm{INT}\left[\frac{2K}{3}\right]$$

where K is the data word and I is the proper tabular entry in C1TAB

The data word corresponding to range is a time, in seconds, between zero crossings of the low frequency modulation on the CW carrier. The frequency of modulation is defined by the unpacked LTEMP1 data word.

The wavelengths of these three modulation frequencies are approximately 22,000, 5,500 and 1,100 statute miles. Thus, in many cases, the vehicle's range is such that several complete cycles of the modulation frequency are completed during the round trip transmission time. The instrumentation measures the difference between zero crossings, but is unable to measure the number of completed cycles. The orbit determination program must compute the number of complete cycles, then add the measured difference to determine the range.

This ambiguity resolution capability is implemented by the following equations:

$$K = \mathrm{INT}\left[(S_n - S_d) \times FR + .5\right]$$

Where S_n is the nominal round trip time in seconds

S_d is the data time, in seconds

FR is the modulation frequency, in c/s

Thus, $S_n - S_d$ is the approximate round trip time of the signal, in seconds. $(S_n - S_d) \times FR$ converts this to the number of cycles of the modulation frequency in the round trip path.

The added constant, 0.5, assures that round-off error does not cause the ambiguity resolver to be off by one complete cycle.

The time (in seconds) of the round trip signal is then found from:

$$T = K/FR + S_d$$

Where K (found above) is the integer number of cycles in the path

FR is the frequency of the signal

S_d is the data

K/FR is the number of seconds in the computed integer number of cycles. Added to this is the data, S_d, which is the amount of time of the remaining fraction of a cycle.

The range is computed by multiplying the round trip time by the velocity of light.

Range Rate

The data in the range rate system is the number of seconds required to count a pre-selected number of Doppler (plus bias) cycles.

The conversion from the units of the data (seconds) to units of range rate (ER/HR) is given by the equation:

$$\dot{\rho} = \frac{C}{2f} \left(K - \frac{N}{\Delta t}\right)$$

Where C is the velocity of light

f is the up frequency (defined by C3TAB)

K is the bias frequency (defined by C3TAB)

N is the preselected cycle count (defined by C2TAB)

Δt is the data.

47.7.2 Time Correction in the Goddard $R/\dot{R}$ System

Range

The time assigned to the range data is the time that the measured signal leaves the satellite. The time on the data tape is the time the measurement at the ground station is started. Thus,

$$T_d = T_K + \Delta T - \frac{TRT}{2}$$

Where T_d is the time assigned to the data

T_K is the time of the data as defined by the data tape

ΔT is the measured data

TRT is the round trip transmission time.

Range Rate

The time assigned to the range rate data is the time that the measured signal leaves the satellite. The time on the data tape is the time the measurement at the ground station is started:

$$T_d = T_K + \frac{\Delta T - TRT}{2}$$

47.7.3 Translation of the State Transition Matrix Across a Reference Body Change

The state transition matrix is modified when the trajectory is referenced to a new body.

$$\Lambda_{(t,t_o)} = \Lambda_{2(t,t_r)} \; S_2^{-1} \; S_1 \; \Lambda_{1(t_r,t_o)}$$

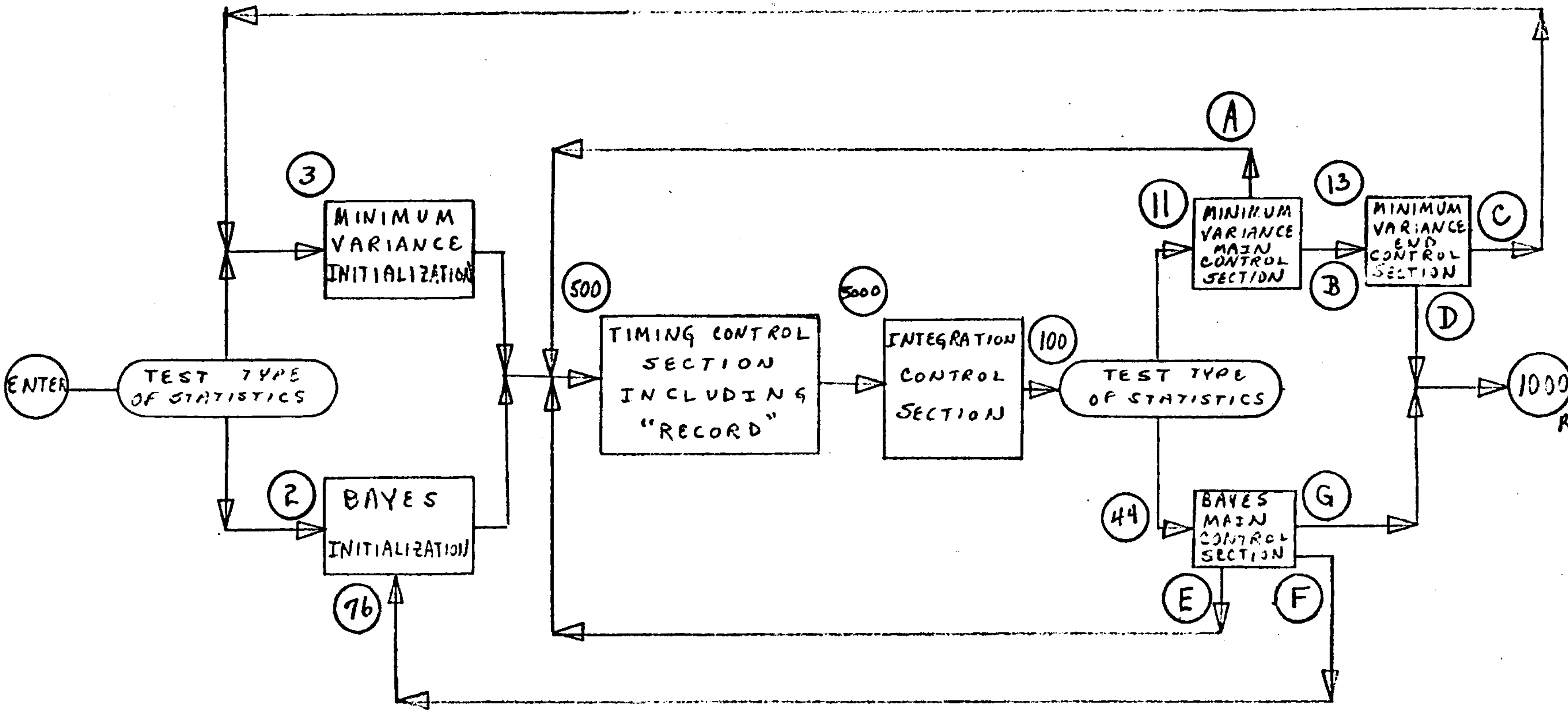
Where $\Lambda_{1(t_o,t_r)}$ is the state transition matrix in the first reference system

S_{t1} reference system at the rectification time, t_r

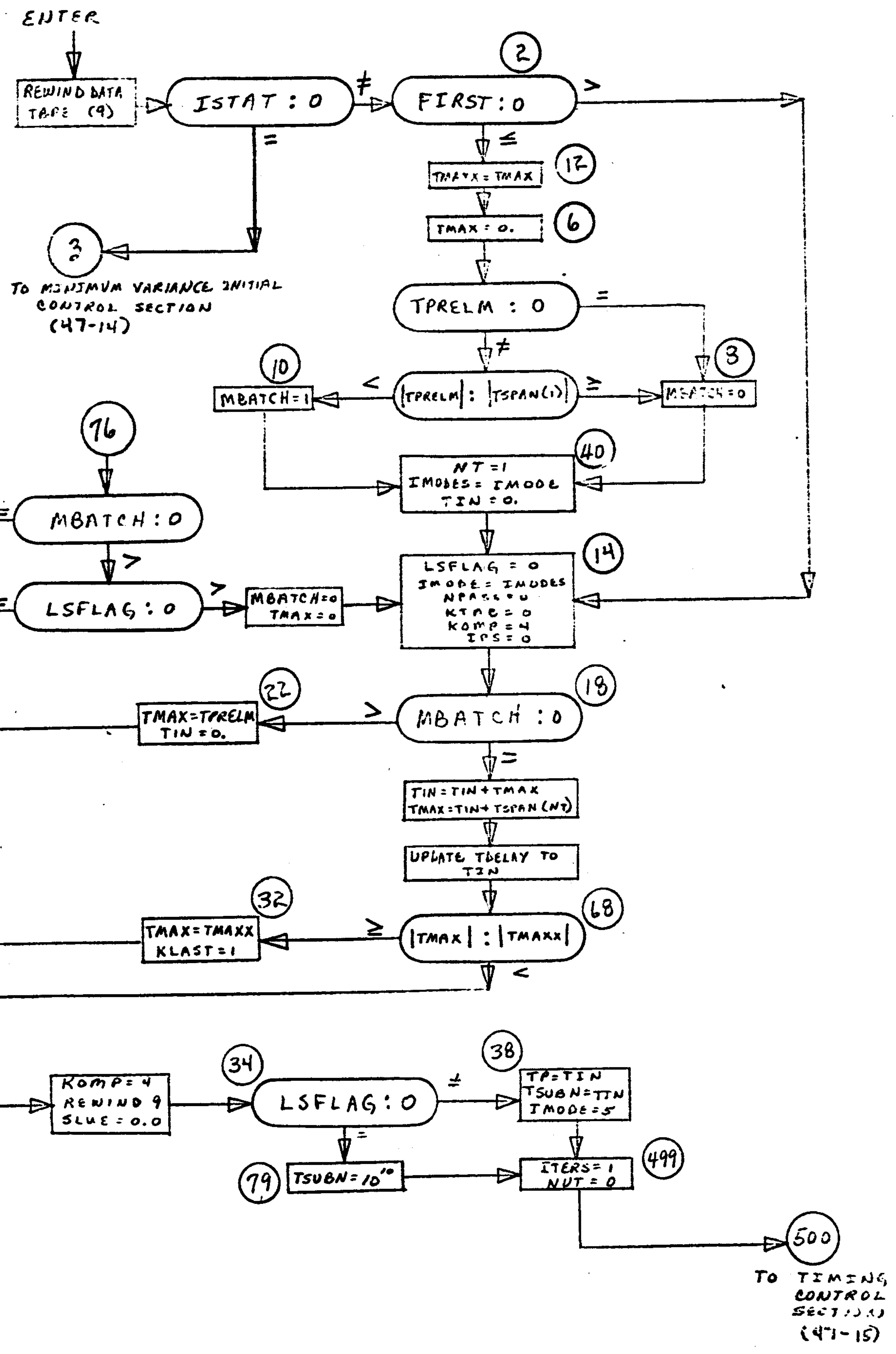
S_{t2}^{-1} is the S^{-1} matrix evaluated in the second reference system at the rectification time, t_r

$\Lambda_{2(t_r,t)}$ is the state transition matrix in the second reference system.

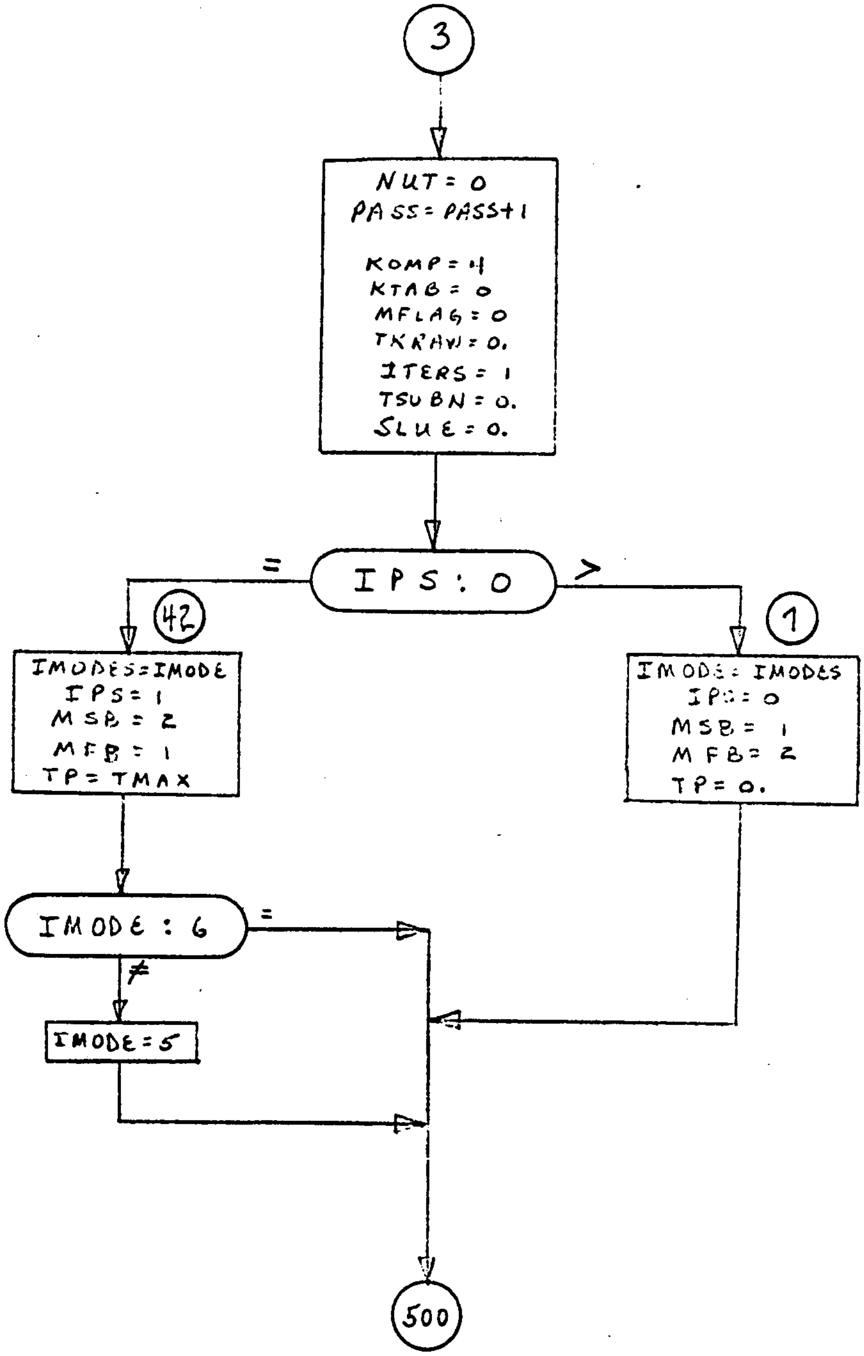
47.? FLOW DIAGRAM -



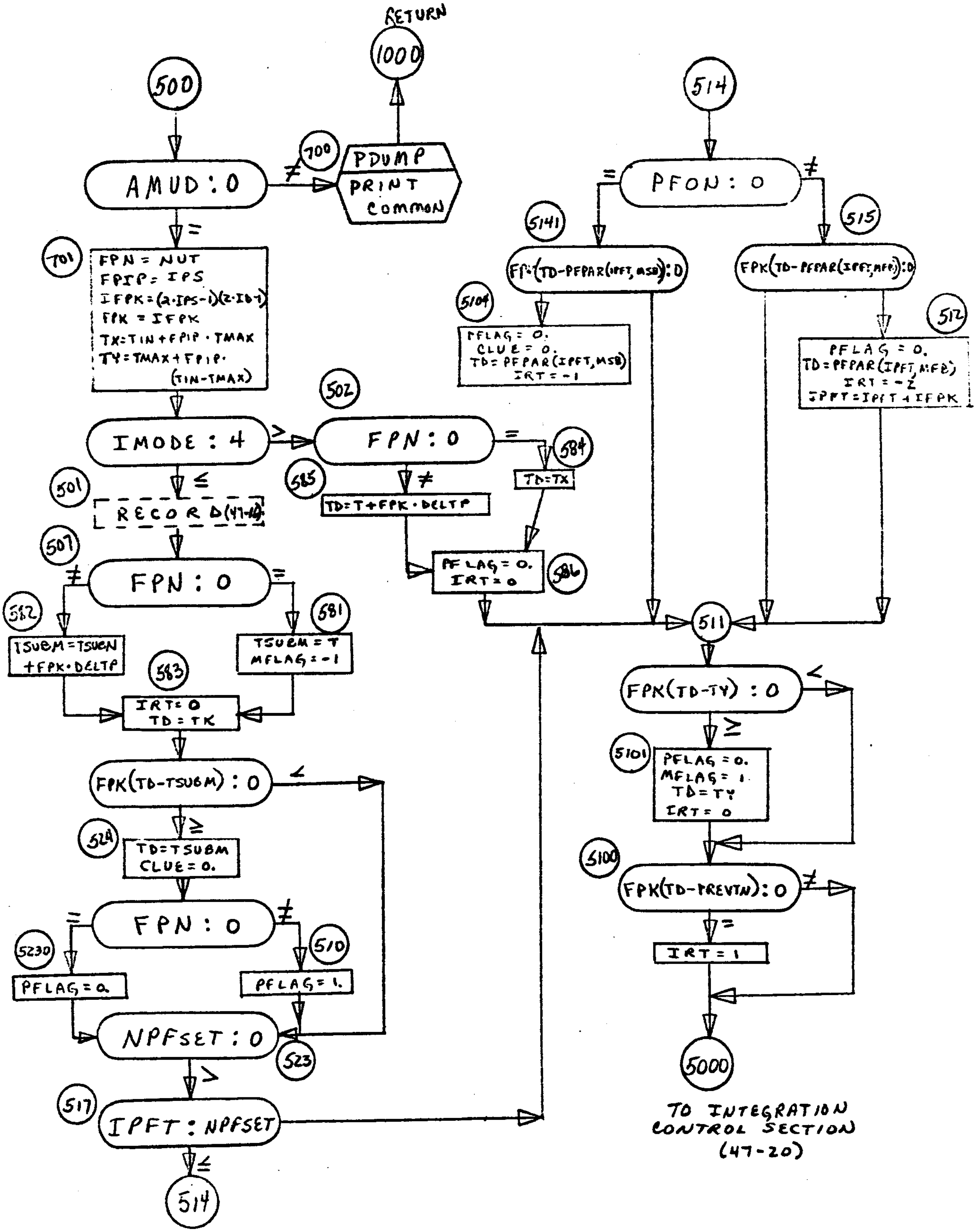
A. Returns to timing control section after processing data point or print point.
B. Goes to M.V. end control section when TMAX is reached.
C. Returns to M.V. initialization section when all criteria for stopping are not met.
D. Returns to EXECB1 when all criteria for ending are met or if SUMARY is requested.
E. Return to timing control section if all criteria for "end of batch" are not met.
F. Returns to least squares initialization section if convergence is not achieved.
G. Returns to EXECB1 if all criteria for "end of batch" and convergence are met.


ENTER
REWIND DATA TAPE (9)
ISTAT : 0
FIRST : 0
TO MINIMUM VARIANCE INITIAL CONTROL SECTION (47-14)
TMAXX = TMAX
TMAX = 0.
TPRELM : 0
MBATCH=1
|TPRELM| : |TSPAN(1)|
MBATCH=0
NT = 1
IMODES = IMODE
TIN = 0.
MBATCH : 0
LSFLAG : 0
MBATCH=0
TMAX=0
LSFLAG = 0
IMODE = IMODES
NPASS = 0
KTAPE = 0
KOMP = 4
IPS = 0
TMAX=TPRELM
TIN = 0.
MBATCH : 0
TIN = TIN + TMAX
TMAX = TIN + TSPAN (NT)
UPDATE TDELAY TO TIN
TMAX=TMAXX
KLAST=1
|TMAX| : |TMAXX|
KOMP = 4
REWIND 9
SLUE = 0.0
LSFLAG : 0
TP=TIN
TSUBN=TIN
IMODE=5
TSUBN = 10^10
ITERS = 1
NUT = 0
TO TIMING CONTROL SECTION (47-15)

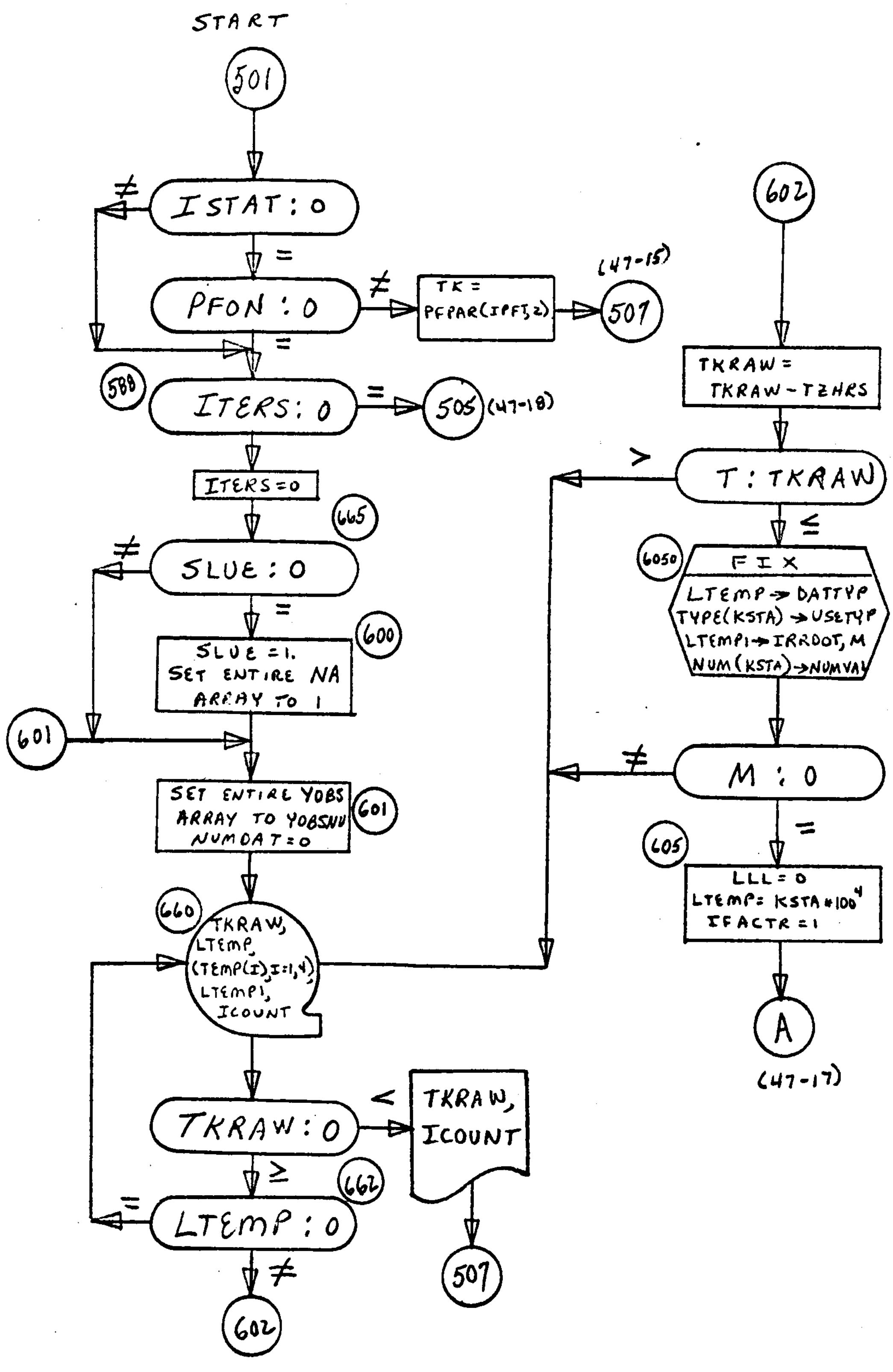
MAINE1 Continued - MINIMUM VARIANCE INITIAL CONTROL SECTION

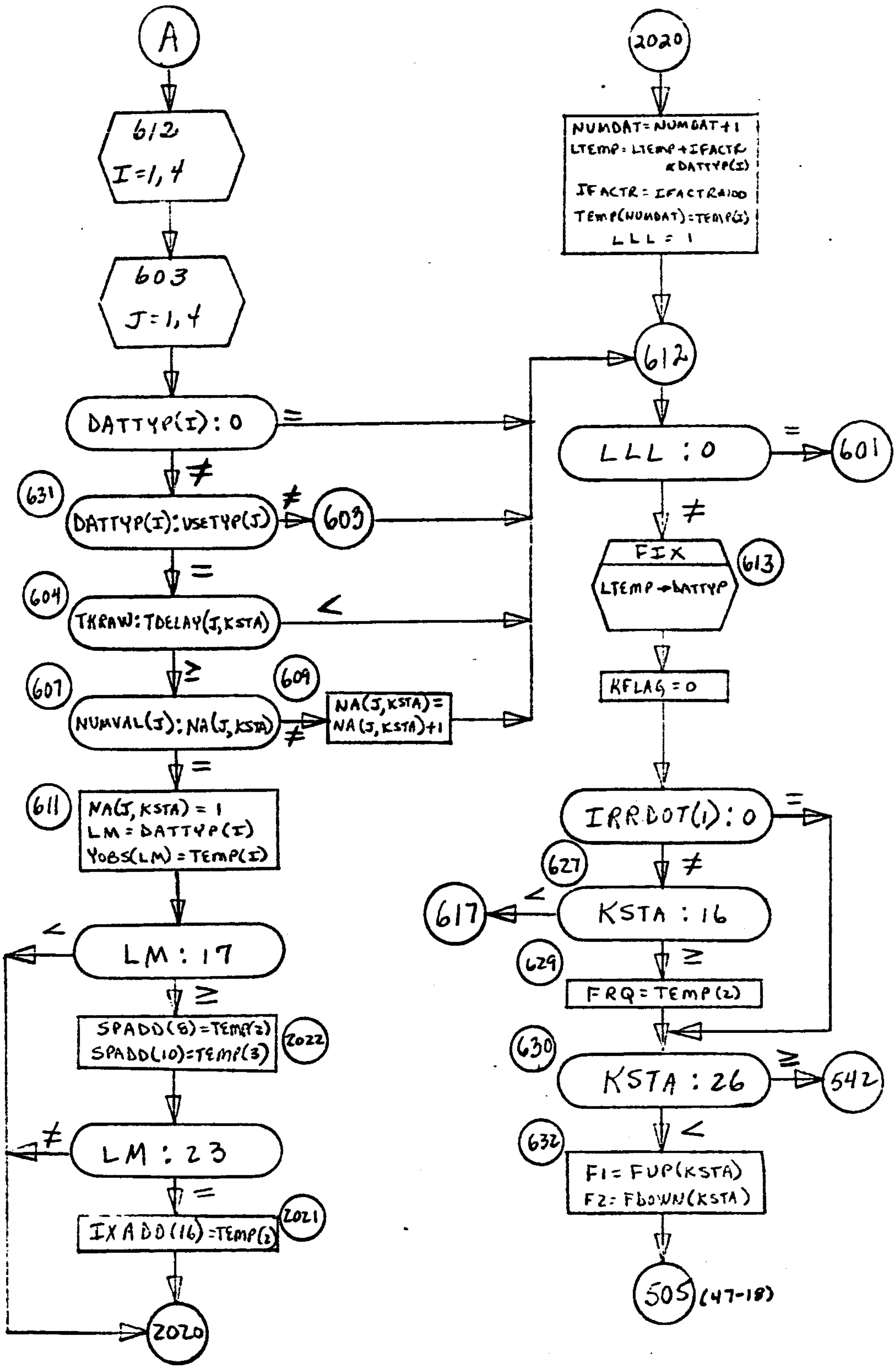


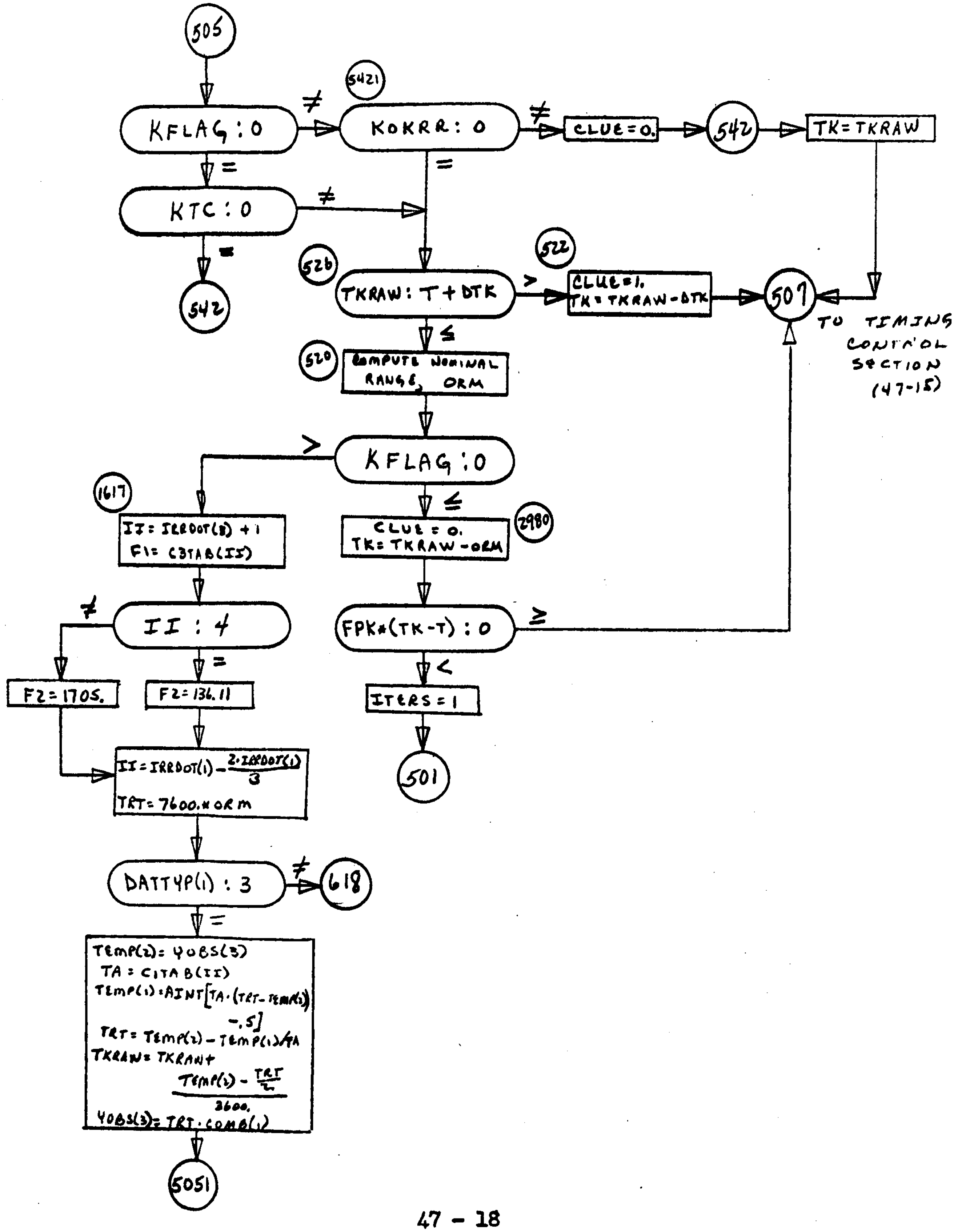
TO TIMING CONTROL
SECTION
(47-15)

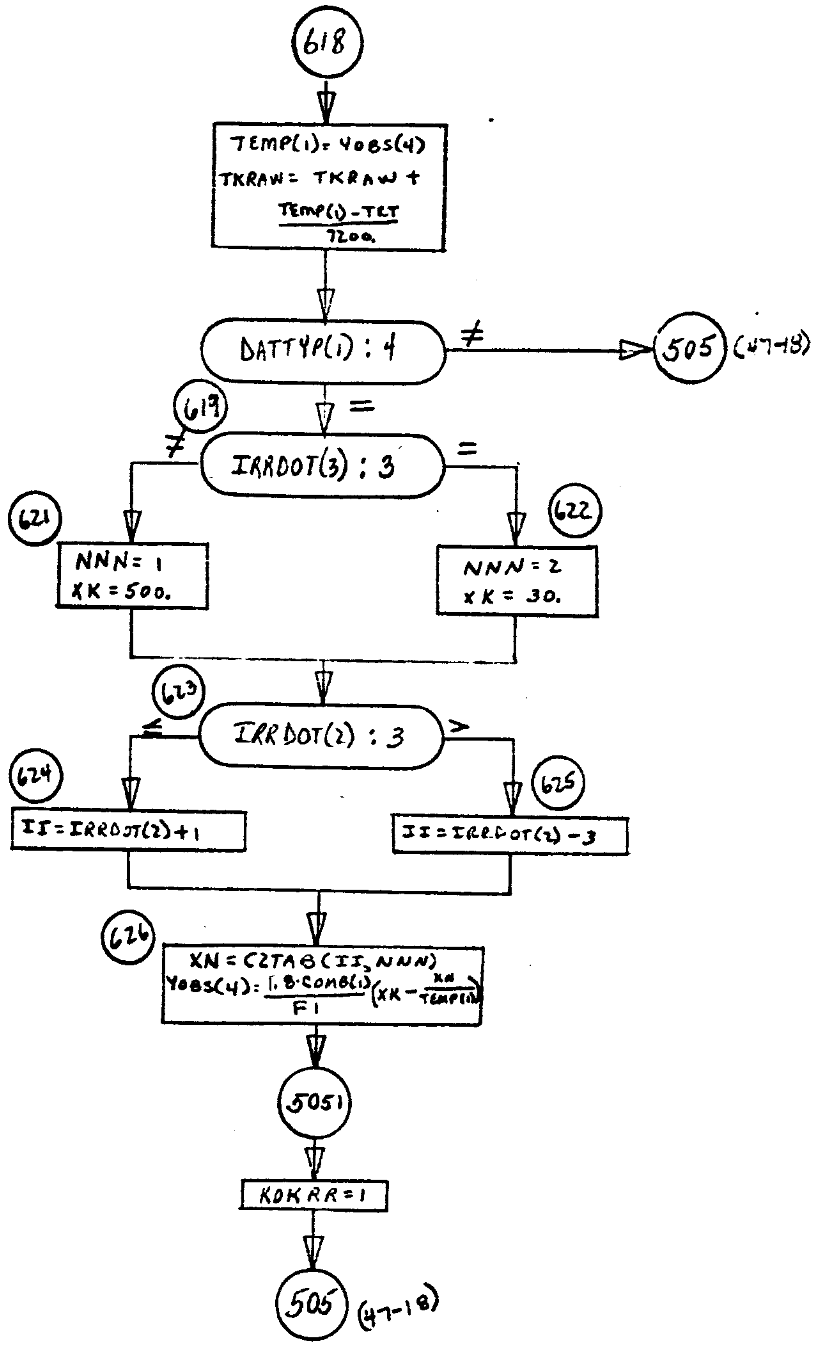


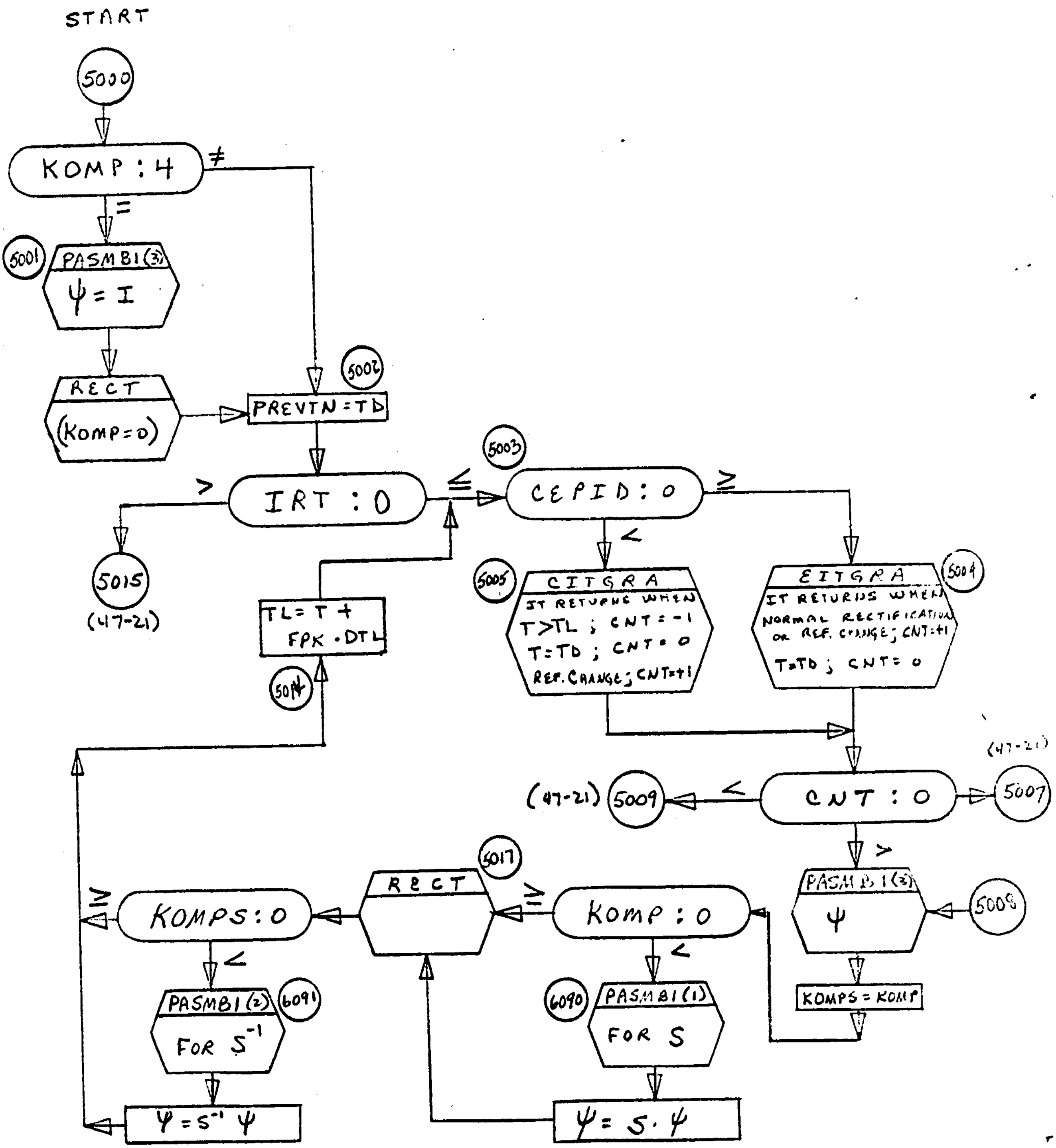
RETURN
1000
500
AMUD : 0
700
PDUMP
PRINT COMMON
701
FPN = NUT
FPIP = IPS
IFPK = (2·IPS-1)(2·ID-1)
FPK = IFPK
TX = TIN + FPIP · TMAX
TY = TMAX + FPIP · (TIN-TMAX)
IMODE : 4
502
FPN : 0
584
TD = TX
585
TD = T + FPK · DELTP
501
RECORD (47-18)
507
FPN : 0
586
PFLAG = 0.
IRT = 0
582
TSUBM = TSUBN + FPK · DELTP
581
TSUBM = T
MFLAG = -1
583
IRT = 0
TD = TK
FPK(TD-TSUBM) : 0
524
TD = TSUBM
CLUE = 0.
FPN : 0
5230
PFLAG = 0.
510
PFLAG = 1.
NPFSET : 0
523
517
IPFT : NPFSET
514
PFON : 0
5141
FPK(TD-PFPAR(IPFT,MSB)) : 0
515
FPK(TD-PFPAR(IPFT,MFB)) : 0
5104
PFLAG = 0.
CLUE = 0.
TD = PFPAR(IPFT,MSB)
IRT = -1
512
PFLAG = 0.
TD = PFPAR(IPFT,MFB)
IRT = -2
IPFT = IPFT + IFPK
511
FPK(TD-TY) : 0
5101
PFLAG = 0.
MFLAG = 1
TD = TY
IRT = 0
5100
FPK(TD-PREVTN) : 0
IRT = 1
5000
TO INTEGRATION CONTROL SECTION (47-20)

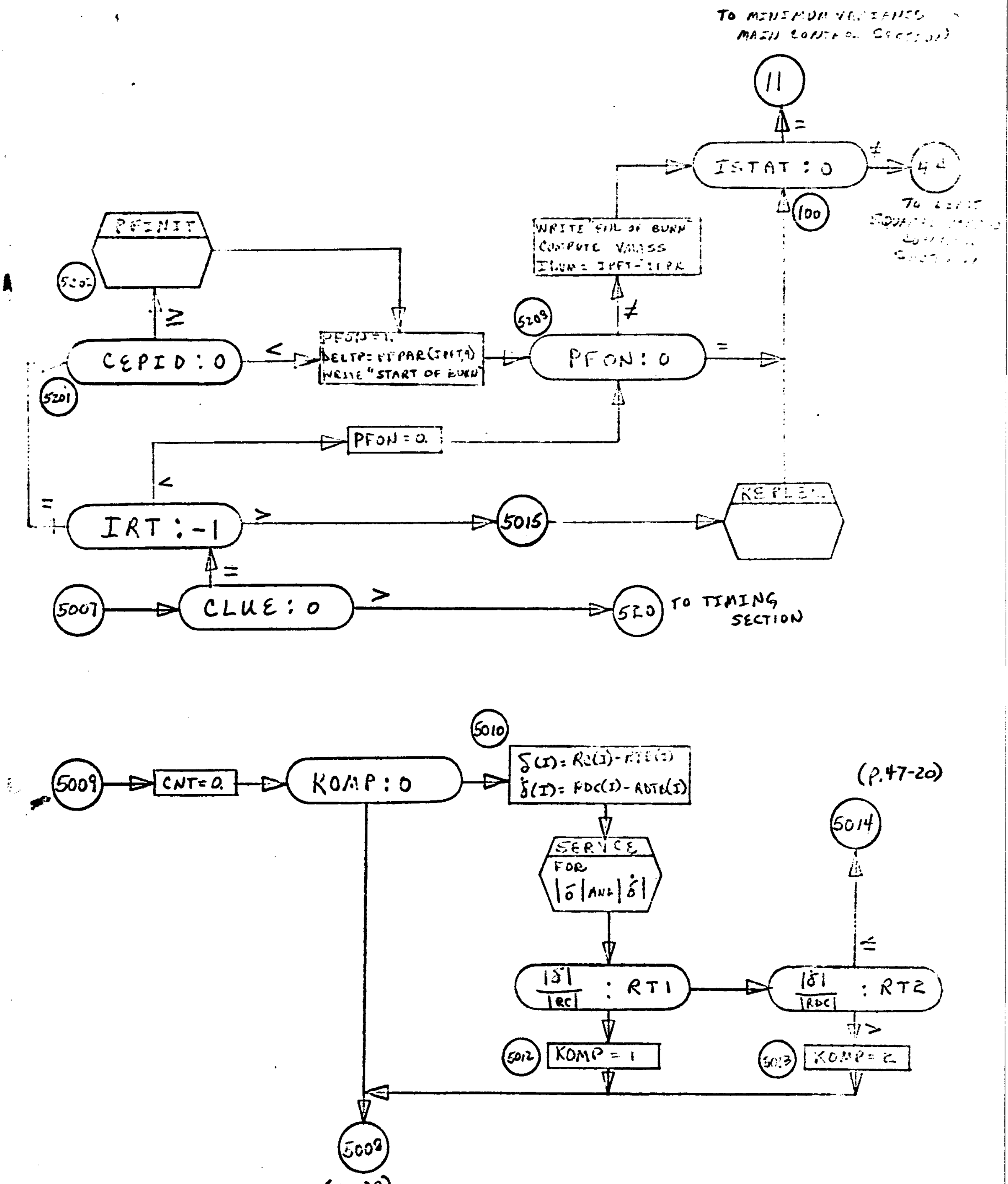

START
501
ISTAT : 0
≠
=
PFON : 0
≠
TK = PFPAR(IPFT,2)
(47-15)
507
=
588
ITERS : 0
=
505
(47-18)
ITERS=0
665
SLUE : 0
≠
=
600
SLUE =1.
SET ENTIRE NA ARRAY TO 1
601
SET ENTIRE YOBS ARRAY TO YOBSNU
NUMDAT=0
601
660
TKRAW, LTEMP, (TEMP(I),I=1,4), LTEMP1, ICOUNT
TKRAW : 0
<
TKRAW, ICOUNT
507
≥
662
LTEMP : 0
=
≠
602
602
TKRAW = TKRAW-TZHRS
T : TKRAW
>
≤
6050
FIX
LTEMP → DATTYP
TYPE(KSTA) → USETYP
LTEMP1 → IRRDOT, M
NUM(KSTA) → NUMVAL
M : 0
≠
=
605
LLL = 0
LTEMP= KSTA*100⁴
IFACTR =1
A
(47-17)

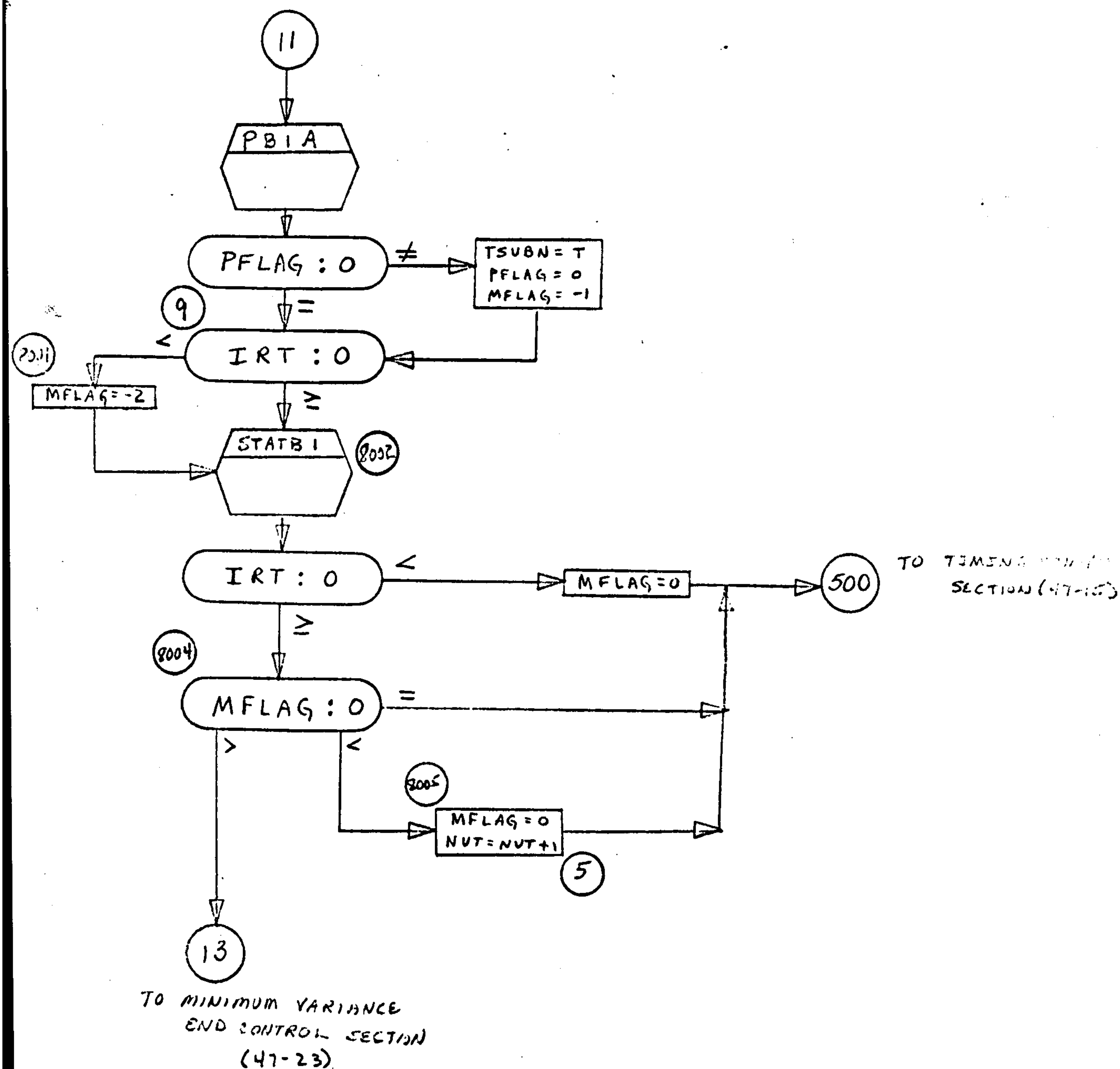

A
612
I=1,4
603
J=1,4
DATTYP(I):0
=
≠
631
DATTYP(I):USETYP(J)
≠
603
=
604
TKRAW:TDELAY(J,KSTA)
<
≥
607
609
NUMVAL(J):NA(J,KSTA)
≠
NA(J,KSTA)=NA(J,KSTA)+1
=
611
NA(J,KSTA) = 1
LM = DATTYP(I)
YOBS(LM) = TEMP(I)
LM : 17
<
≥
SPADD(8)=TEMP(2)
SPADD(10)=TEMP(3)
2022
LM : 23
≠
=
IXADD(16)=TEMP(2)
2021
2020
2020
NUMDAT=NUMDAT+1
LTEMP=LTEMP+IFACTR*DATTYP(I)
IFACTR=IFACTR*100
TEMP(NUMDAT)=TEMP(I)
LLL = 1
612
LLL : 0
=
601
≠
FIX
LTEMP→DATTYP
613
KFLAG=0
IRRDOT(1):0
=
≠
627
KSTA : 16
<
617
629
≥
FRQ=TEMP(2)
630
KSTA : 26
≥
542
632
<
F1=FUP(KSTA)
F2=FDOWN(KSTA)
505
(47-18)

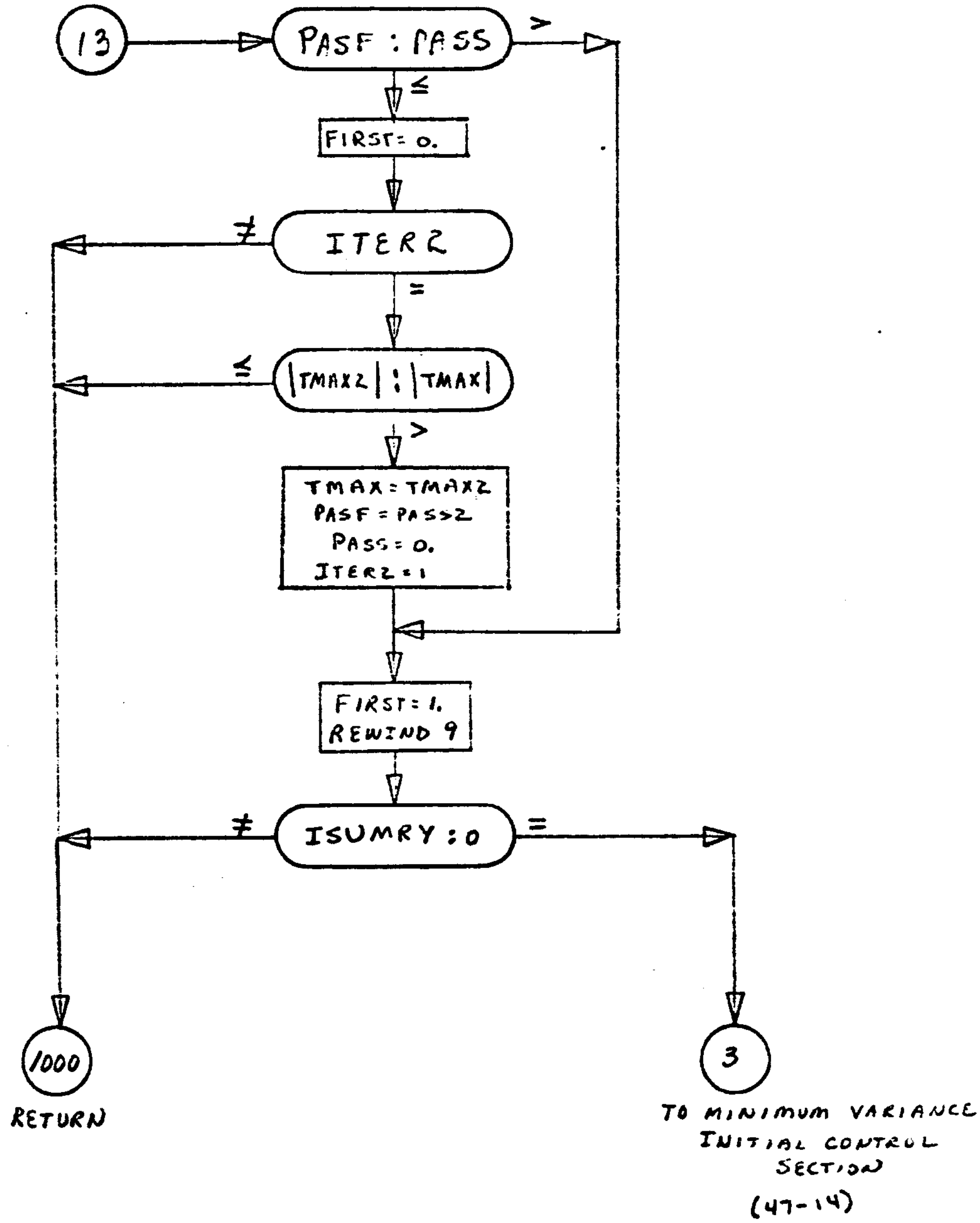

505
KFLAG : 0
5421
KOKRR : 0
CLUE=0.
542
TK=TKRAW
KTC : 0
542
526
TKRAW : T+DTK
522
CLUE=1.
TK=TKRAW-DTK
507
TO TIMING CONTROL SECTION (47-15)
520
COMPUTE NOMINAL RANGE, ORM
KFLAG : 0
1617
II=IRRDOT(3)+1
F1=C3TAB(II)
2980
CLUE=0.
TK=TKRAW-ORM
II : 4
FPK*(TK-T) : 0
F2=170.5.
F2=136.11
ITERS=1
501
TRT=7600.*ORM
DATTYP(1) : 3
618
TEMP(2)=YOBS(3)
TA=C1TAB(II)
5051

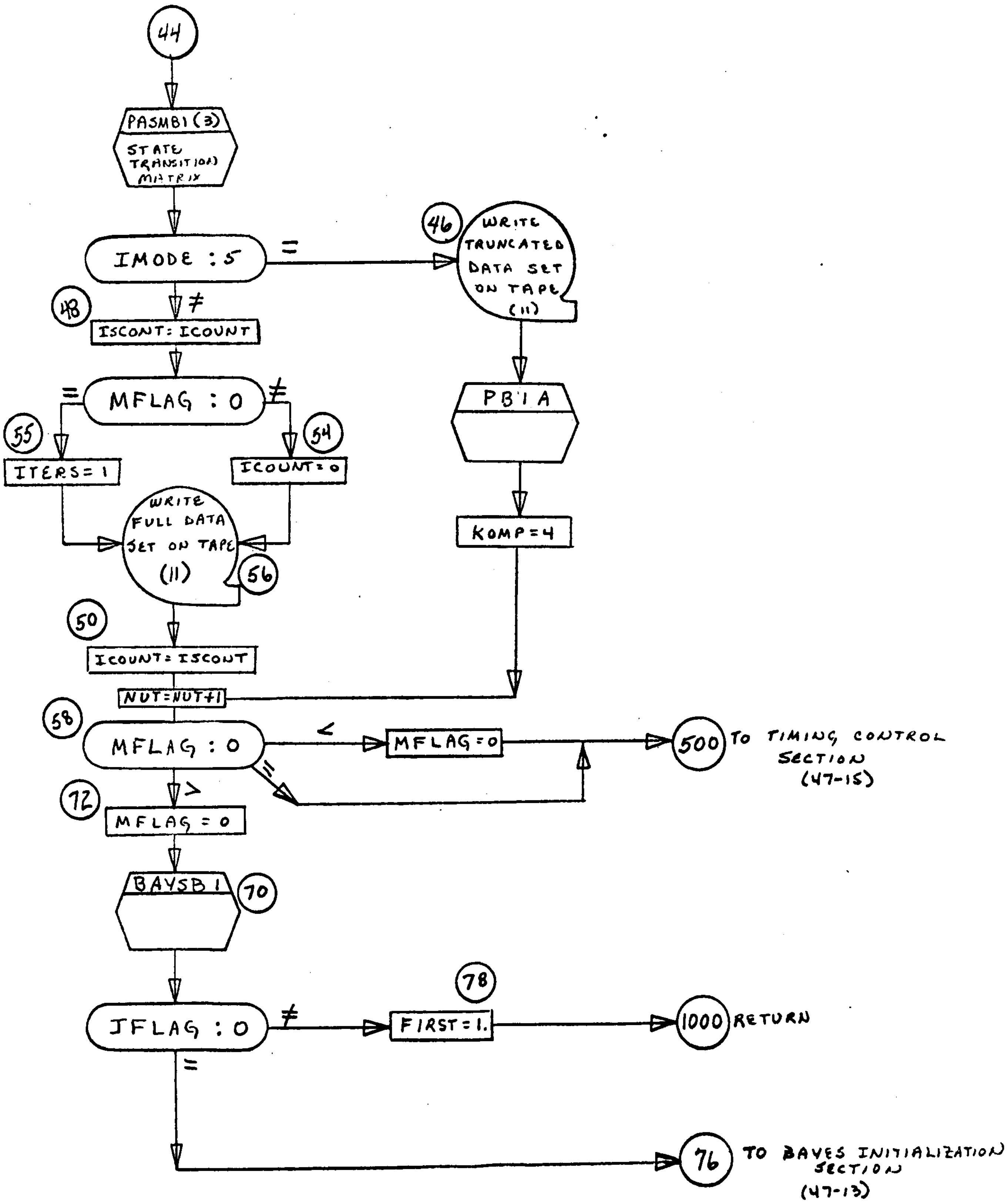

618
TEMP(1) = YOBS(4)
TKRAW = TKRAW + TEMP(1) - TCT / 7200.
DATTYP(1) : 4
≠
505 (47-18)
=
619
IRRDOT(3) : 3
≠
=
621
NNN = 1
XK = 500.
622
NNN = 2
XK = 30.
623
IRRDOT(2) : 3
≤
>
624
II = IRRDOT(2) + 1
625
II = IRRDOT(2) - 3
626
XN = C2TAB(II, NNN)
YOBS(4) = 1.8·COMB(1) / F1 (XK - XN / TEMP(1))
5051
KOKRR = 1
505 (47-18)


START
5000
KOMP : 4
≠
=
5001
PASMB1(3)
ψ = I
RECT
(KOMP=0)
5002
PREVTN = TD
IRT : 0
>
5015
(47-21)
≤
5003
CEPID : 0
≥
<
5005
CITGRA
IT RETURNS WHEN
T>TL ; CNT = -1
T=TD ; CNT = 0
REF. CHANGE; CNT=+1
5004
EITGRA
IT RETURNS WHEN
NORMAL RECTIFICATION
OR REF. CHANGE; CNT=+1
T=TD ; CNT = 0
TL = T + FPK · DTL
5014
(47-21)
5009
<
CNT : 0
5007
(47-21)
>
PASMB1(3)
ψ
5008
KOMPS = KOMP
5017
RECT
≥
KOMP : 0
<
6090
PASMB1(1)
FOR S
ψ = S · ψ
KOMPS : 0
≥
<
PASMB1(2)
6091
FOR S^{-1}
$\psi = S^{-1}\psi$


TO MINIMUM VARIANCE MAIN CONTROL SECTION
11
ISTAT : 0
44
TO LEAST SQUARES MAIN CONTROL SECTION
100
WRITE "END OF BURN"
COMPUTE VALUES
PFINIT
5202
5203
CEPID : 0
PFON = 1.
DELTP = PFPAR(INIT9)
WRITE "START OF BURN"
PFON : 0
5201
PFON = 0.
KEPLER
IRT : -1
5015
5007
CLUE : 0
520
TO TIMING SECTION
5010
5009
CNT = 0.
KOMP : 0
(p.47-20)
5014
SERVICE FOR
KOMP = 1
KOMP = 2
5012
5013
5008
(47-20)


11
PB1A
PFLAG : 0
≠
TSUBN = T
PFLAG = 0
MFLAG = -1
=
9
IRT : 0
<
MFLAG = -2
≥
STATB1
8002
IRT : 0
<
MFLAG = 0
500
≥
8004
MFLAG : 0
=
>
<
8005
MFLAG = 0
NUT = NUT+1
5
13
TO MINIMUM VARIANCE
END CONTROL SECTION
(47-23)


13
PASF : PASS
>
≤
FIRST = 0.
ITERZ
≠
=
|TMAXZ| : |TMAX|
≤
>
TMAX = TMAXZ
PASF = PASSZ
PASS = 0.
ITERZ = 1
FIRST = 1.
REWIND 9
ISUMRY : 0
≠
=
1000
RETURN
3
TO MINIMUM VARIANCE INITIAL CONTROL SECTION
(47-14)


44
PASMB1 (3)
STATE TRANSITION MATRIX
IMODE : 5
=
≠
46
WRITE TRUNCATED DATA SET ON TAPE (11)
48
ISCONT = ICOUNT
MFLAG : 0
55
ITERS = 1
54
ICOUNT = 0
WRITE FULL DATA SET ON TAPE (11)
56
PB1A
KOMP = 4
50
ICOUNT = ISCONT
NUT = NUT + 1
58
MFLAG : 0
<
>
MFLAG = 0
500
TO TIMING CONTROL SECTION (47-15)
72
MFLAG = 0
BAYSB1
70
JFLAG : 0
78
FIRST = 1.
1000
RETURN
76
TO BAYES INITIALIZATION SECTION (47-13)

48. Subroutine MATINV (AMATRX, II, JJ, M)

48.1 Purpose

This subroutine inverts a non-singular matrix. The inverted matrix may overwrite the input matrix or be stored in a new array, depending on the calling sequence.

48.2 Method

The Gauss-Jordan elimination method is used to invert the Matrix.

The program first stores the A matrix into the B matrix and then performs the inversion on the latter matrix.

48.3 Program References

MATINV is called by:

B1 - BAYSB1, INPTB1, STATB1

B2 - B2INPT, BYSB2, STTB2

48.4 I/O Data

48.4.1 Inputs

AMATRX - double precision matrix to be inverted

II - actual square dimension of AMATRX ($\leq$ 26)

JJ - actual square dimension of BMATRX ($\leq$ 26)

M - square size of matrix to invert

48.4.2 Outputs

BMATRX - the double precision inverted matrix

This may also be AMATRX

48.5 Symbols Used

PIVOT - pivot element

SWAP - temporary storage

ICOL - current column

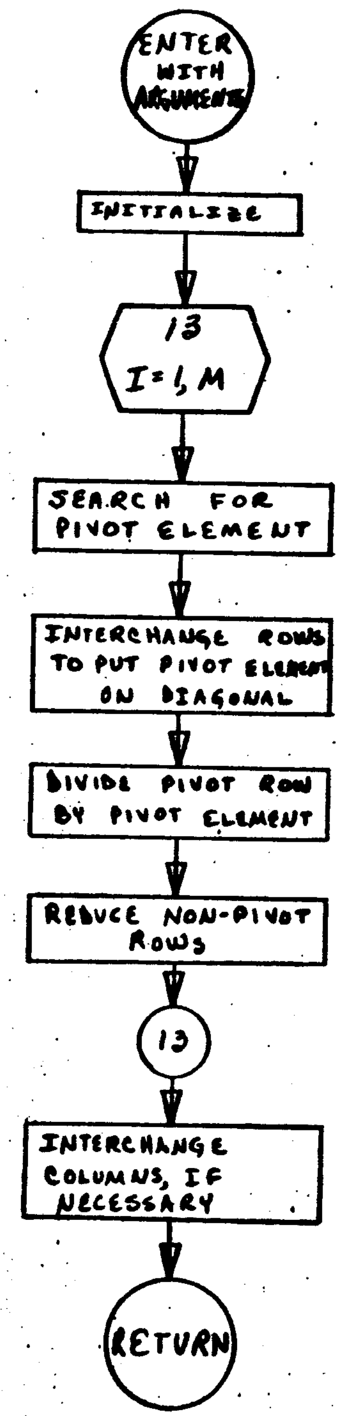
INDEX (26, 2) - saved row and column of each pivot element

IROW - current row

TEMP1 (26) - indicator for whether column has been used as pivot element

48.6 Equations Used

See any standard numerical analysis text.


ENTER WITH ARGUMENTS
INITIALIZE
13
I=1, M
SEARCH FOR PIVOT ELEMENT
INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
DIVIDE PIVOT ROW BY PIVOT ELEMENT
REDUCE NON-PIVOT ROWS
13
INTERCHANGE COLUMNS, IF NECESSARY
RETURN

49. Subroutine OBSRB1

49.1 Purpose

This subroutine computes the observables as seen from a ground station. It applies corrections for refraction and assigns proper time tags to the time of transmission and reception of the signal at the ground station.

49.2 Method

The time, station number, data types and vehicle location are transmitted to this subroutine. The observables are computed and the refraction correction to each is computed, if requested. The differences between the computed and observed data are principal outputs.

49.3 Program References

49.3.1 OBSRB1 is called by:

STATB1

49.3.2 OBSRB1 calls:

DDOT, DMTML, DOMUD, FIX, FLORNG, MODELA, STAPOS

49.4 I/O Data

49.4.1 Inputs from COMMON

CDS, COMB, CPOS, CVEL, EMIN, EPSSQ, ERAD, FRQ, OVB, PRENUT, RC, RCMSC, RDC, STAC, STAHT, STALT, STAOR, T, TK, TKRAW, TWOPI
DH1, DH2, EBRMLT, F1, F2, H2, H4, IGUESS, IMODE, KRF, LTEMP, LTEMP1, MPLUS1, MPLUS2, MPLUS3, MPLUS4, MWREF, ONE, RMEAN, STATYP, TEBAR, TWO

49.4.2 Outputs to COMMON

DELY, EBAR, OBSPLS, ORM, OVB, OVSB, RCMSC, T, TSSA, YCOM, YOBS, YRTEMP, YTEMP
AMUD, AREJ, DATTYP, EBRVAL , IGUESS, KM, KSTA, NCDST, NUMDAT, RNGFLG

49.4.3 Other Inputs and Outputs

None

49.5 Symbols Used

49.5.1 COMMON Symbols

HACC, TPMAT1, TPMAT2, TPMAT4, TPMAT5, TPMAT9, XNNEW

49.5.2 Refraction Portion Symbols

See OBSERA (32.5.2)

49.5.3 Other Symbols

ALPNM (3, 3) - transformation matrix from station topocentric coordinate to true topocentric coordinates

CA - cosine YCOM (1)

CE - cosine YCOM (2)

DEN - magnitude of the component of ORM projected onto the horizontal plane

OREBD - east component of ORM in topocentric system

ORHSD - up component of ORM in topocentric system

ORM2 - square of ORM

ORNSD - north component of ORM in topocentric system

SA - sine YCOM (1)

SE - sine YCOM (2)

TEMAL (8) - temporary allocation

VCMSC (3) - vector between reference body center and vehicle

VRM - magnitude of VCMSC vector

I - index

ISAVJ (4) - saved indices used in forming EBAR matrix

IZY - flag word

K - index

KSTAT (5) - (Data)- station numbers of paired DSN stations

KTEMP - saved value of KSTA

KX - index used for observation types in STAOR array

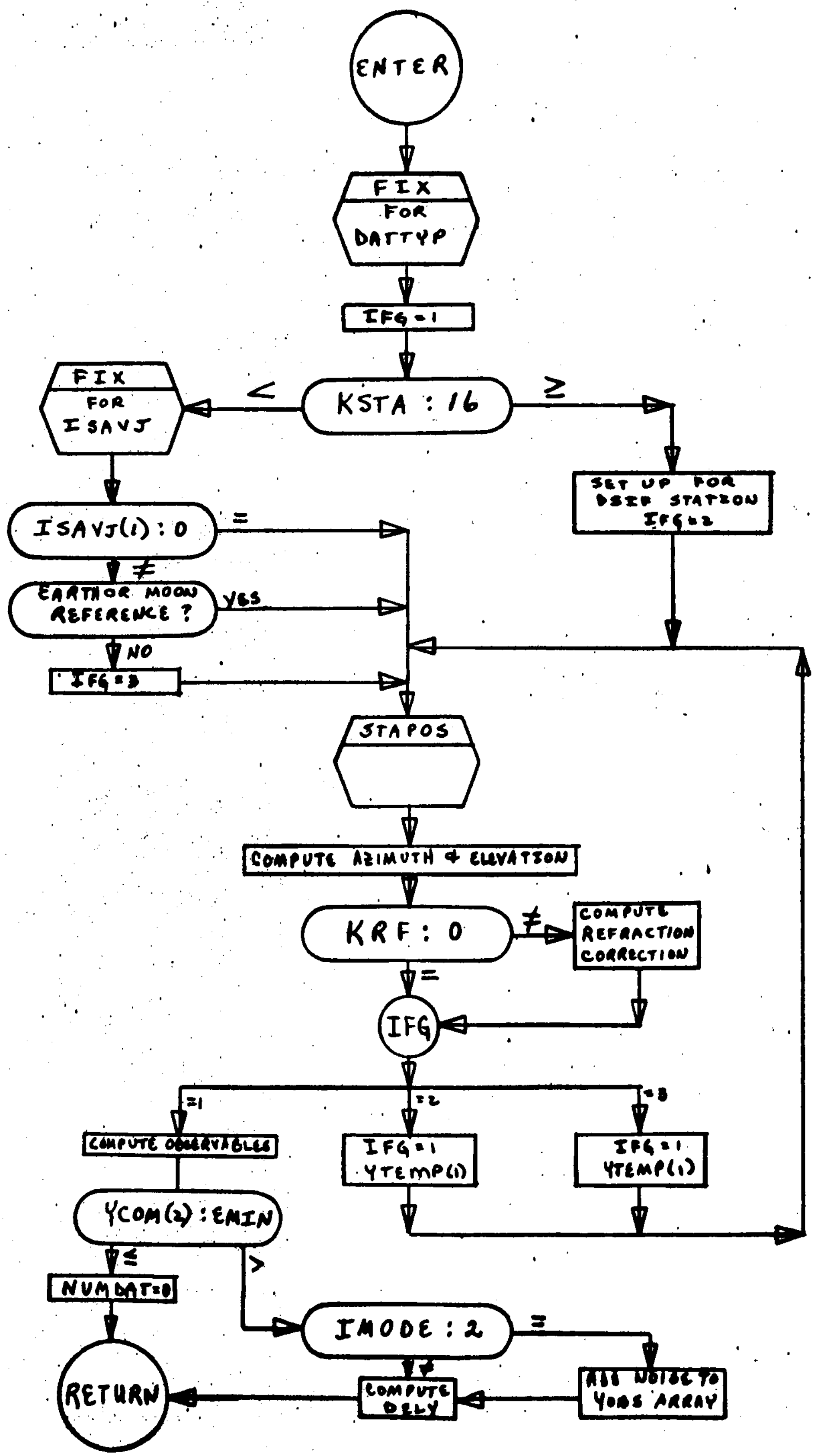
M - temporary variable

49.6 Equations Used

See Ref. 1, Section 6.2

See Ref. 1, Appendix C for Refraction Correction

49.7 Flow Diagram - OBSRB1



50. Subroutine ONOBS

50.1 Purpose

This subroutine computes the on-board observations in the Minimum Variance links.

50.2 Method

The relative location of the vehicle with respect to planets and stars is used to compute the proper observation value.

50.3 Program References

50.3.1 ONOBS is called by:

STATB1

50.3.2 ONOBS calls

DDOT, FIX, FLORNG, SERVCE, STAPOS

50.4 I/O Data

50.4.1 Inputs from COMMON

CPOS, PI, RC, STAC, STAOR, TWOPI
EBRMLT, IGUESS, IMODE, ISTAR, LTEMP, MAXLUN, MPLUS1, MPLUS2, MWREF,
NCDST, ONE, POSLUN, RADII, RMEAN, STAR, STATYP, TEBAR, TWO

50.4.2 Outputs to COMMON

DELY, EBAR, OBSPLS, STALN, STALT, YCOM, YOBS, YRTEMP, YTEMP
DATTYP, EBRVAL, KM, KSTA, NUMDAT

50.4.3 Other Inputs and Outputs

None

50.5 Symbols Used

50.5.1 COMMON Symbols

TPMAT4, TPMT10

50.5.2 Other Symbols

KJ - flag

KP - flag

KX - index for S[illegible]R array

M - index for data type

NUMDTT - saved NUMDAT

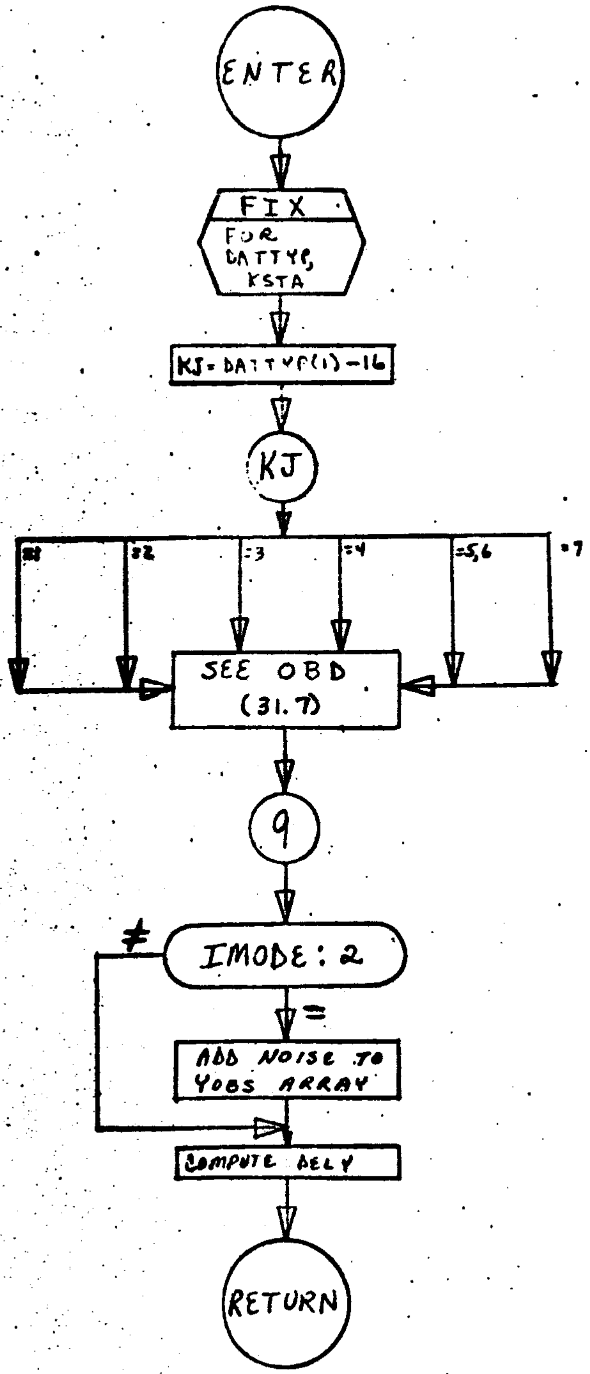
RTEMP - temporary storage

RTEMP1 - temporary storage

50.6 Equations Used

See Ref. 1, Section 6.

50.7 FLOW DIAGRAM - ONOBS



51. Subroutine ONPTL

51.1 Purpose

This subroutine computes the on-board partials of observations with respect to vehicle position and velocity for the Minimum Variance link.

5.1.2 Method

Each row of the M matrix (SAVEL1) is done corresponding to the type of measurement in which the first 3 columns correspond to the position vector and the second 3 to the velocity vector.

51.3 Program References

51.3.1 ONPT1 is called by:

STATB1

51.3.2 ONPTL calls:

DDOT, SERVCE

51.4 I/O Data

51.4.1 Inputs from COMMON

CPOS, OBSPIS, RC, RDC, STAC, YCOM, YRTEMP, YTEMP
IXADD(16), MPLUS1, MPLUS3, MVREF, NUMDAT, RADII, TWO

51.4.2 Outputs to COMMON

SAVEL1
NUMDAT

51.4.3 Other Inputs and Outputs

None

51.5 Symbols Used

51.5.1 COMMON Symbols

TPMAT4, TPMAT6, TPMAT7, TPMAT8, TPMAT9

51.5.2 Other Symbols

ICOL - current column

IROW - current row

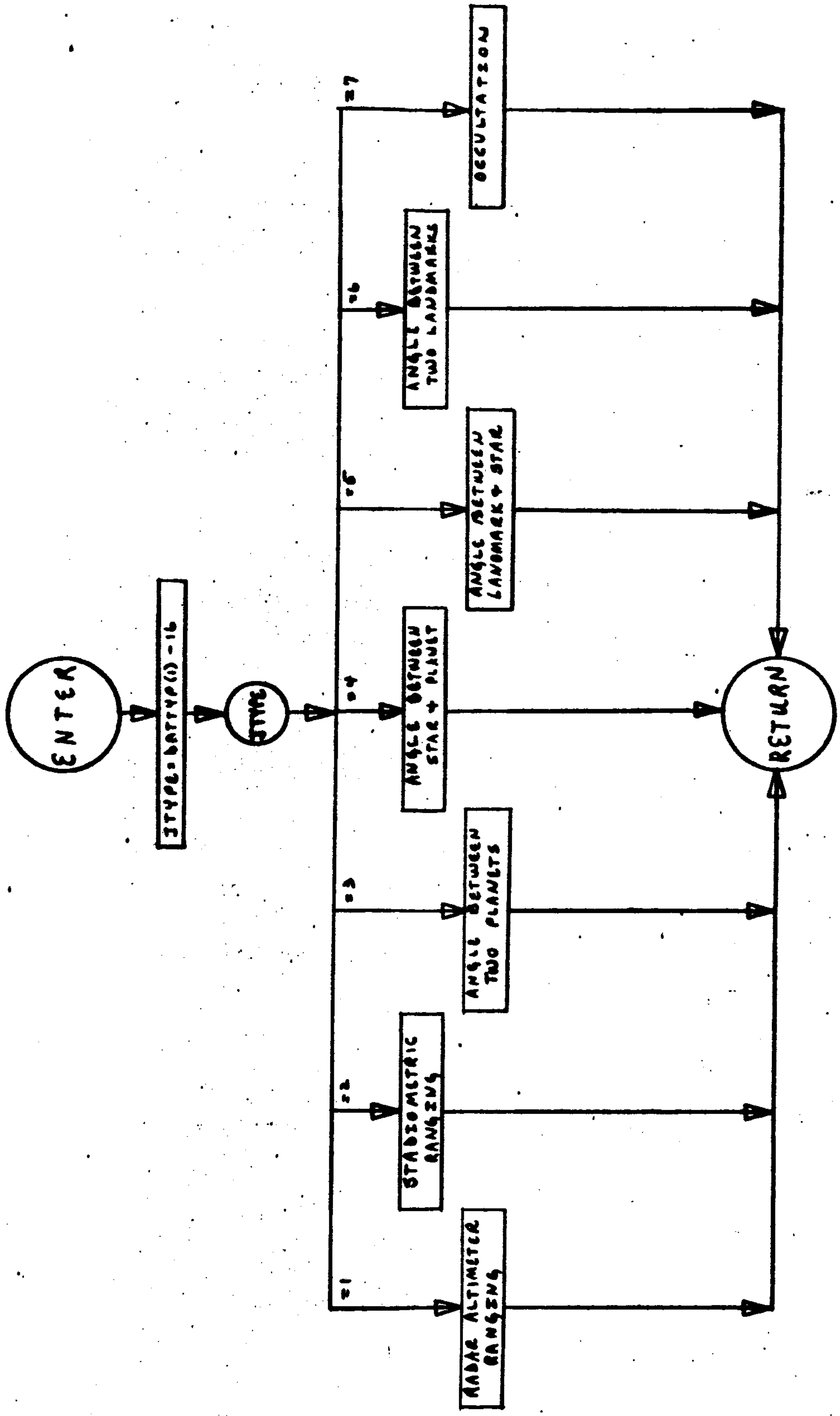
JT[illegible] current type - 16

KTYPE - index

51.6 Equations Used

See Ref. 1, Section 6.3.4.

51.7 FLOW DIAGRAM - CNFTL



52. Subroutine PASMB1 (IFLAG)

52.1 Purpose

This subroutine computes the S, S^{-1} or state transition matrix depending on IFLAG.

52.2 Method

When IFLAG = 1, compute S is SMAT

When IFLAG = 2, compute S^{-1} in SMAT

When IFLAG = 3, compute state transition

Matrix in ALAM1. If KOMP = 4, unity matrix

In Bayes statistics, when KOMP = 0, the State Transition Matrix is stored in STAT. It is the accumulated matrix from time 0, rather than from the last data point as is done in Minimum Variance.

52.3 Program References

52.3.1 PASMB1 is called by:

BAYSB1, INPTB1, STATB1

52.3.2 PASMB1 calls:

DDOT, DMTML, DOMUD, SERVCE

52.4 I/O Data

52.4.1 Inputs from COMMON

BETA, EF1, EF2, EF6, EF7, HMU, RC, RDC, RDI, RDTB, RI, RTB, SQTMU, TBF, TBFD, TBG, TBGD, XFAC
ISTAT, KOMP, M6, MPLUS1, MPLUS4 , ONE, TWO

52.4.2 Outputs to COMMON

ALAM1, RDTB, RTB, SMAT, STAT

52.4.3 Other Inputs

IFLAG

52.4.4 Other Outputs

None

52.5 Symbols Used

52.5.1 COMMON Symbols

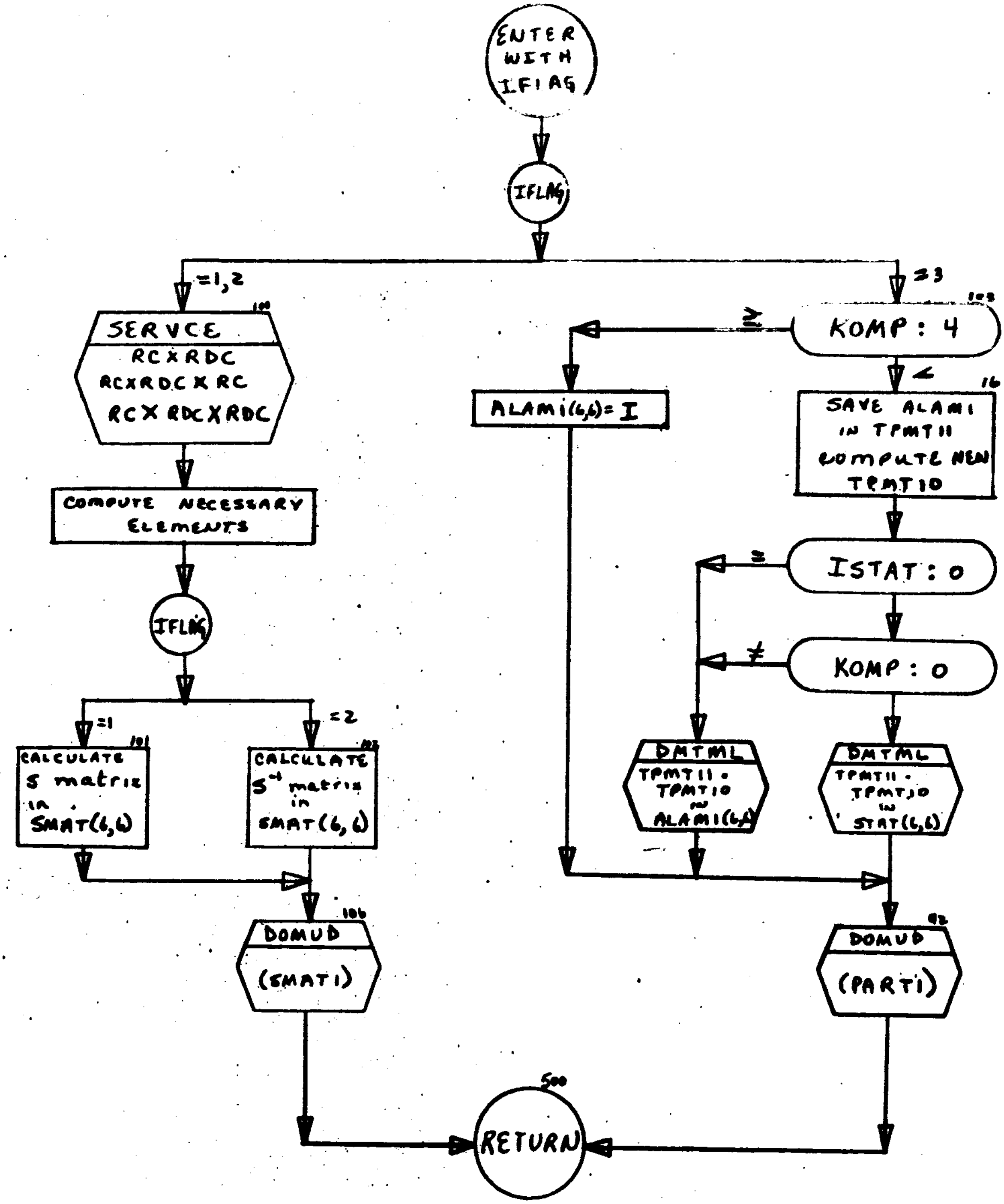
TPMAT, TPMAT1, TPMAT2, TPMAT4, TPMAT5, TPMAT6, TPMAT8, TPMT10, TPMT11

52.5.2 Other Symbols

PART1 - BCD Word = PASMB1
SMAT1 - BCD Word = SMATB1

52.6 Equations Used

See Ref. 1, Section 5.


ENTER WITH IFLAG
IFLAG
=1,2
≥3
100
SERVCE
RCXRDC
RCXRDCXRC
RCXRDCXRDC
COMPUTE NECESSARY ELEMENTS
IFLAG
=1
=2
101
CALCULATE S matrix in SMAT(6,6)
102
CALCULATE S^{-1} matrix in SMAT(6,6)
106
DOMUD
(SMATI)
103
KOMP : 4
≥
<
ALAMI(6,6)= I
16
SAVE ALAMI IN TPMT11 COMPUTE NEW TPMT10
ISTAT : 0
=
KOMP : 0
≠
DMTML
TPMT11 · TPMT10 IN ALAMI(6,6)
DMTML
TPMT11 · TPMT10 IN STAT(6,6)
92
DOMUD
(PARTI)
500
RETURN

53. Subroutine PB1A (NON)

53.1 Purpose

This subroutine prints out pertinent trajectory information.

53.2 Method

If IMODE = 5 or 6, printing is automatically carried out. In all other modes, the subroutine must determine whether it is a print time. If so, it then checks the first 3 values in the IPSEC array. For any non-zero values, the corresponding section is printed. If the value of NON is non-zero, and any of the rest of the IPSEC array are non-zero, subroutine PTB1 is called to print the other sections.

To determine whether it is a print time, the subroutine first checks to see whether the present time is within the print portion (DTPI) of the total print period (TAU). If not, no printing occurs. If so, it next checks the value of the print interval within DTPI (PRATE). If it is negative it automatically prints. If positive and it is the first time into the present print period, printing occurs. Otherwise, no printing is done.

53.3 Program References

53.3.1 PB1A is called by:

BAYSB1, MAINB1

53.3.2 PB1A calls:

PTB1

53.4 I/O Data

53.4.1 Inputs from COMMON

DTP, RC, RDC, SCALE, T, TMAX, TP
DTPI, FPK, IMODE, IPSEC, MPLUS1, MPLUS4, NUMT, NYEARP, PRATE, PVALPH, SIXTY, T/U, TP, TWT4, TZERO

53.4.2 Outputs to COMMON

TP
FKPR, KPRINT, NUMT

53.4.3 Other Inputs

NON

53.4.4 Other Outputs

See Ref. 2, Section 3.2.1 for description of 1st 3 sections of printout.

53.5 Symbols Used

53.5.1 COMMON Symbols

TPMAT4, TPMAT5

53.5.2 Other Symbols

FTAU - fractional part of the print period (TAU)

IPNT - indicator for current section

KPR - indicator to determine next print time

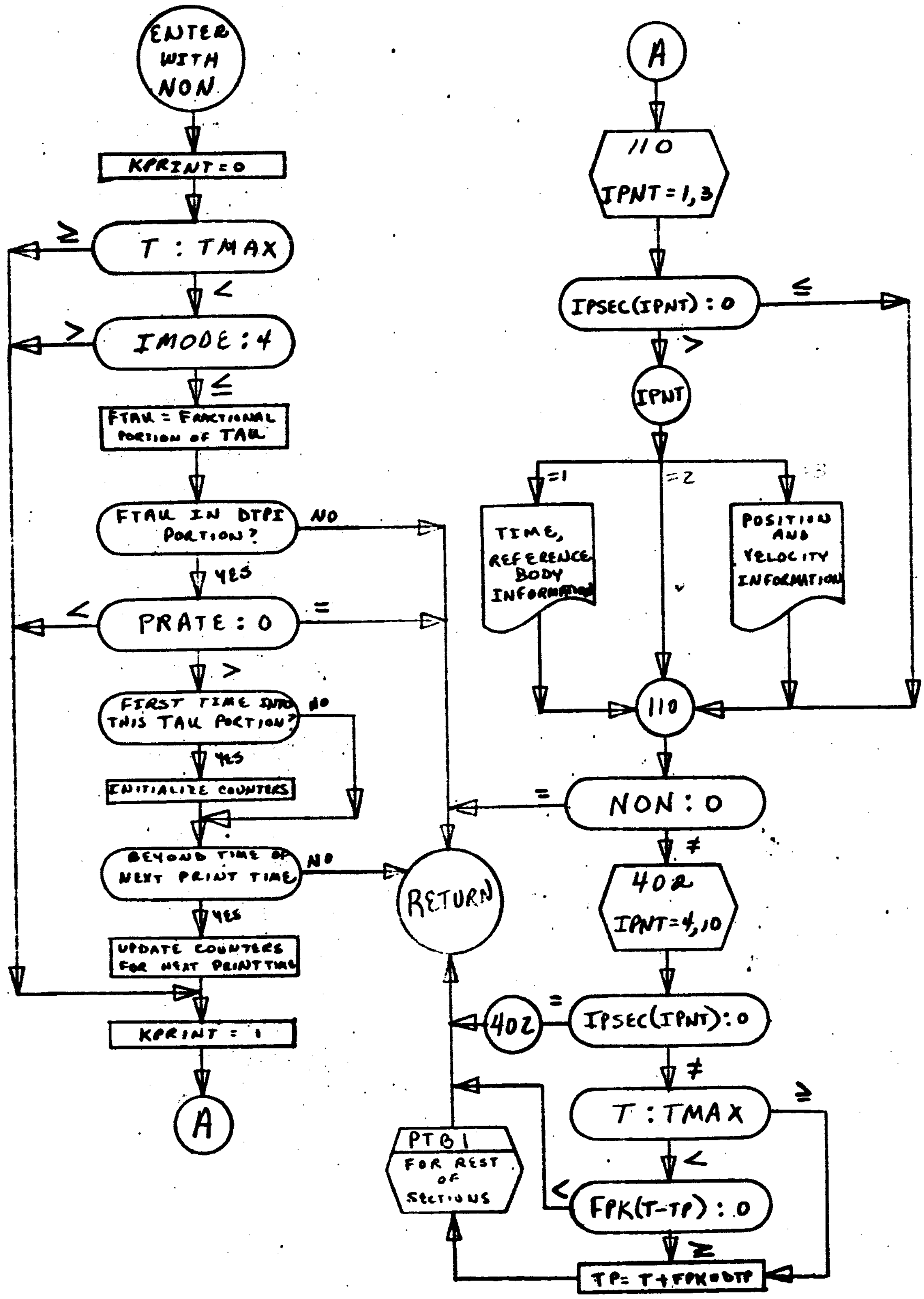
NUMTAU - number of print period being processed

POST - positive value of T

53.6 Equations Used

None

53.7 Flow Diagram - PB1A



54. Subroutine PRNTB1 (KOOK)

54.1 Purpose

This subroutine prints out statistical information.

54.2 Method

After determining that it is a print time from KPRINT, the subroutine checks KSECPR (KOPT, KOOK). If the value is non-zero, the corresponding section is printed.

54.3 Program References

PRNTB1 is called by:

BAYSB1, STATB1

54.4 I/O Data

54.4.1 Inputs from COMMON

ALAM1, ALMAT, CONST, DELALP, DELX, DELY, EBAR, SAVEL1, SCALE, SMAT, STAC, STAT, T, YCOM, YOBS
DATTYP, KOPT, KPRINT, KSECPR, KSTA, MFLAG, NUMDAT, PVALPH

54.4.2 Outputs to COMMON

None

54.4.3 Other Inputs

KOOK

54.4.4 Other Outputs

See Ref. 2, Section 3.2.2

54.5 Symbols Used

54.5.1 COMMON Symbols

TPMAT4

54.5.2 Other Symbols

DATYPE (4) - packed OBTYPE array

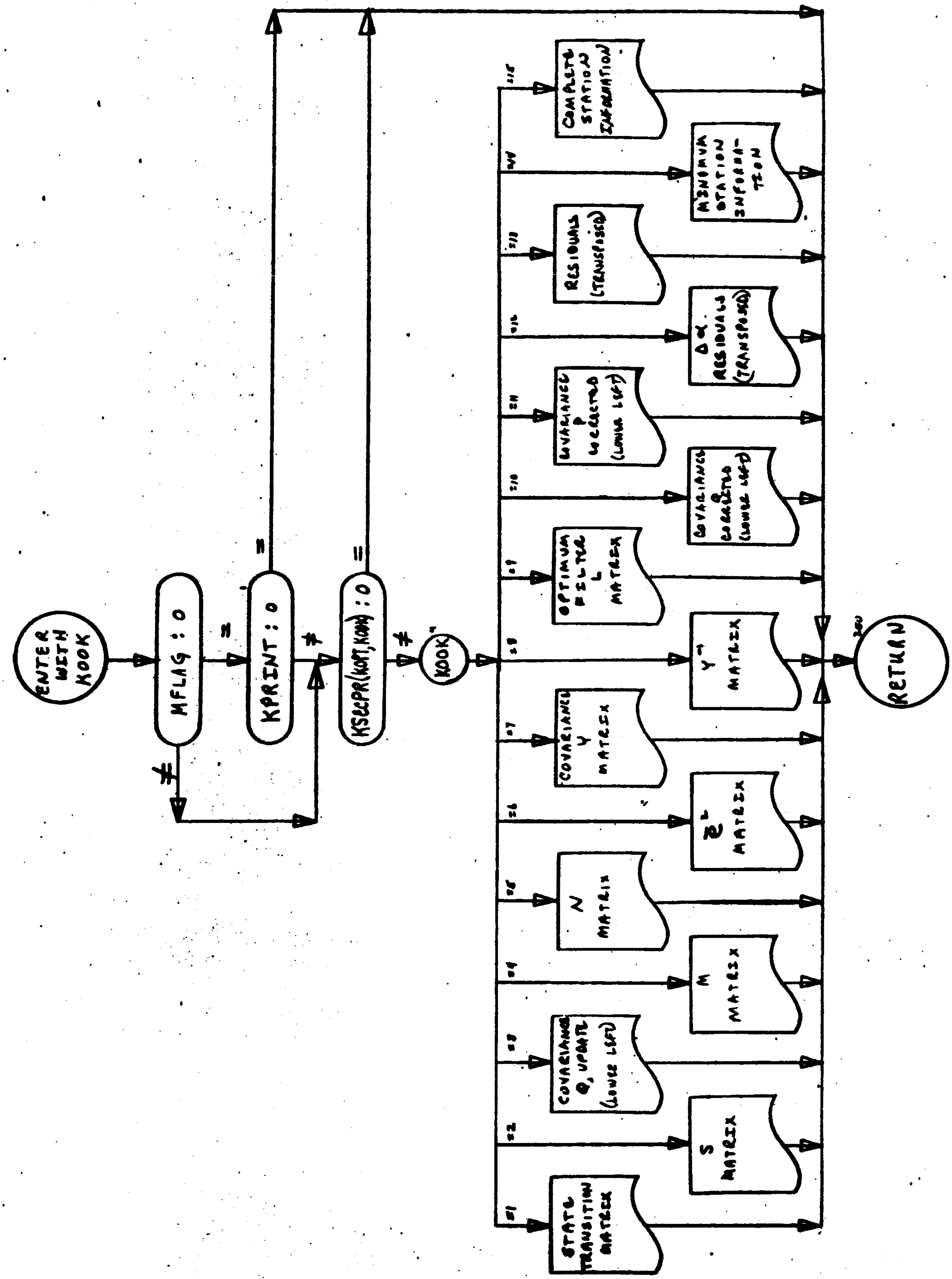
K - index for data type

OBTYPE (25) - BCD data array for the 25 types

OBUNIT (25) - BCD data array for the units of each of the 25 types

54.6 Equations Used

None


ENTER WITH KOOK
MFLAG : 0
KPRINT : 0
KSELPR(KOPT,KOOK) : 0
KOOK
RETURN
STATE TRANSITION MATRIX
S MATRIX
COVARIANCE Q, UPDATE (LOWER LEFT)
M MATRIX
N MATRIX
MATRIX
COVARIANCE Y MATRIX
MATRIX
OPTIMUM FILTER L MATRIX
COVARIANCE Q CORRECTED (LOWER LEFT)
COVARIANCE P CORRECTED (LOWER LEFT)
RESIDUALS (TRANSPOSED)
RESIDUALS (TRANSPOSED)
STATION INFORMATION
COMPLETE STATION INFORMATION

55.1 Purpose

This subroutine prints out pertinent trajectory information.

55.2 Method

Checking each of the 4th through 10th values of the IPSEC array, if any is non-zero, the corresponding section is printed.

55.3 Program References

55.3.1 PTB1 is called by:

PB1A

55.3.2 PTB1 calls:

DDOT, DOMUD, SERVCE

55.4 I/O Data

55.4.1 Inputs from COMMON

CPOS, CRAD, CVEL, DYN, EPSSQ, GAMM, PRENUT, RC, RDC, SCALE, T, TWOPI

CWLIN, MINUS1, MPLUS1, MPLUS2, MPLUS4, MWREF, ONE, PVALPH, TWO

55.4.2 Outputs to COMMON

HMU, SQTMU

AMUD

55.4.3 Other Inputs

None

55.4.4 Other Outputs

See Reference 2, Section 3.2.1 for descriptions of sections 4 through 10.

55.5 Symbols Used

55.5.1 COMMON Symbols

TPMAT4, TPMAT5, TPMAT6, TPMAT7, TPMAT8, TPMAT9

55.5.2 Other Symbols

ESPAL(4,7,2) - (Data) - BCD words for use in printing Section 5

IPNT - Current print section being processed

IT - Temporary storage

NCODE - Index for CPOS and CVEL in printing Section 9.

OSCUL1 - BCD word = OSCUL1

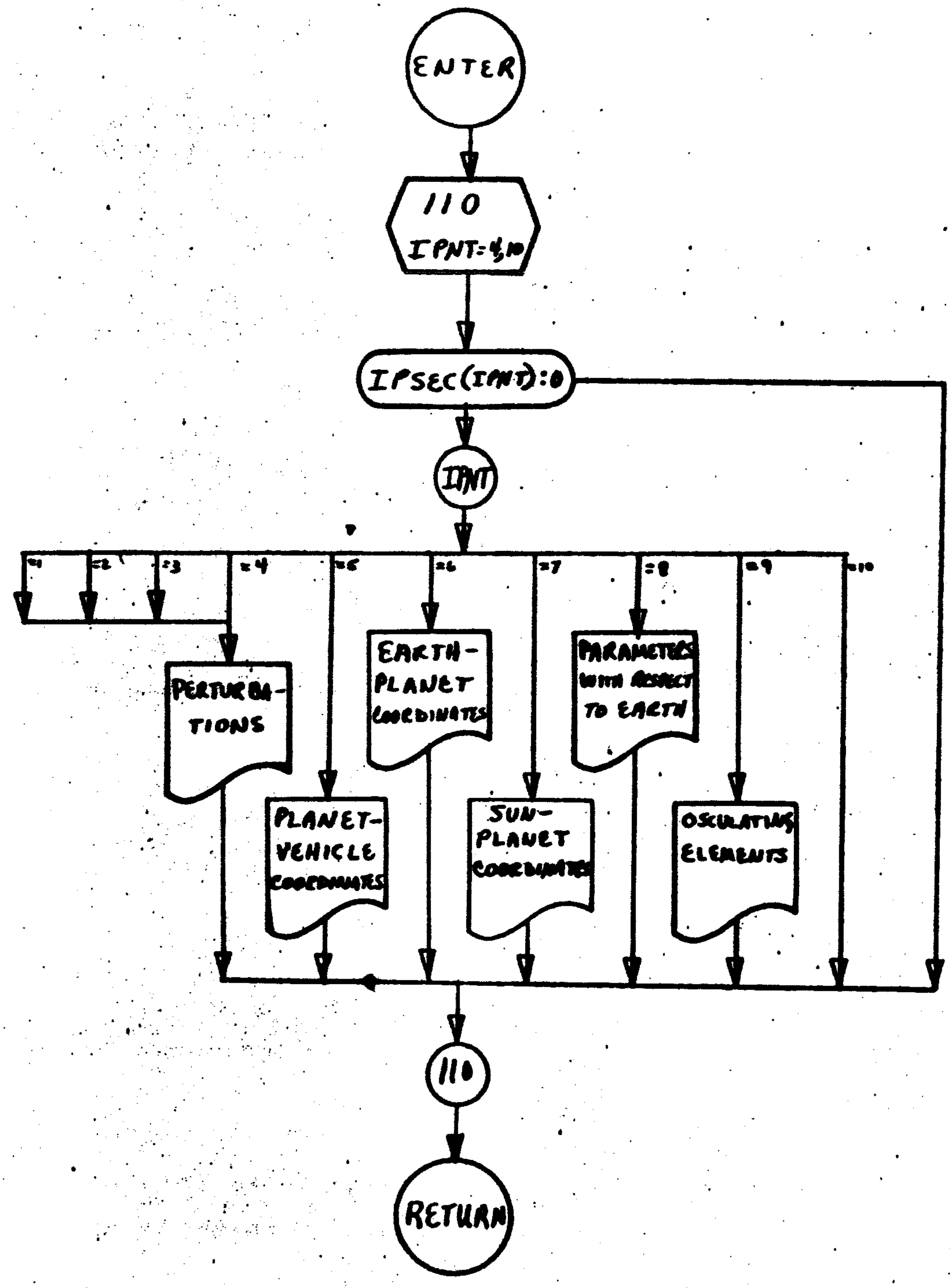
OSCUL2 - BCD word = OSCUL2

PVAL(4,7) - (Data) - BCD words for use in printing Section 5.

55.6 Equations Used

Subsatellite point and osculating element computations follow standard procedures.

55.7 FLOW DIAGRAM - PTB1



56. Subroutine PTISB1

56.1 Purpose

This subroutine computes the ground station partials of the observations with respect to the vehicle position and velocity.

56.2 Method

The matrix is stored in SAVEL1.

56.3 Program References

PTISB1 is called by:

STATB1

56.4 I/O Data

56.4.1 Inputs from COMMON

COMB, CPRT, DELY, FRQ, GHA, OBSPIS, ORM, OVB, RCMSC, YCOM, YOBS, YOBSNU
DATTYP, EBAR, EBRVAL, FUP, KSTA, MPLUS1, MPLUS4, NUMDAT, TWO

56.4.2 Outputs to COMMON

DELY, SAVEL1, YOBS
AREJ, DATTYP, EBAR, EBRVAL, NUMDAT

56.4.3 Other Inputs or Outputs

None

56.5 Symbols Used

56.5.1 COMMON Symbols

TPMAT8

56.5.2 Other Symbols

CA - cosine of computed azimuth

CE - cosine of computed elevation

CX - temporary storage

DXDA - temporary storage

DXDE - temporary storage

SA - sine of azimuth

SE - sine of elevation angle

SEA - temporary storage

SECA - temporary storage

SECE - temporary storage

SXCX - temporary storage

TE - tangent of elevation angle

TMH2 - temporary storage

TORM - temporary storage

XITEMP - temporary storage

XK - temporary storage

ICOL - current column

IROW - current row

J - index

JTYPE - current data type being processed

KX - saved NUMDAT

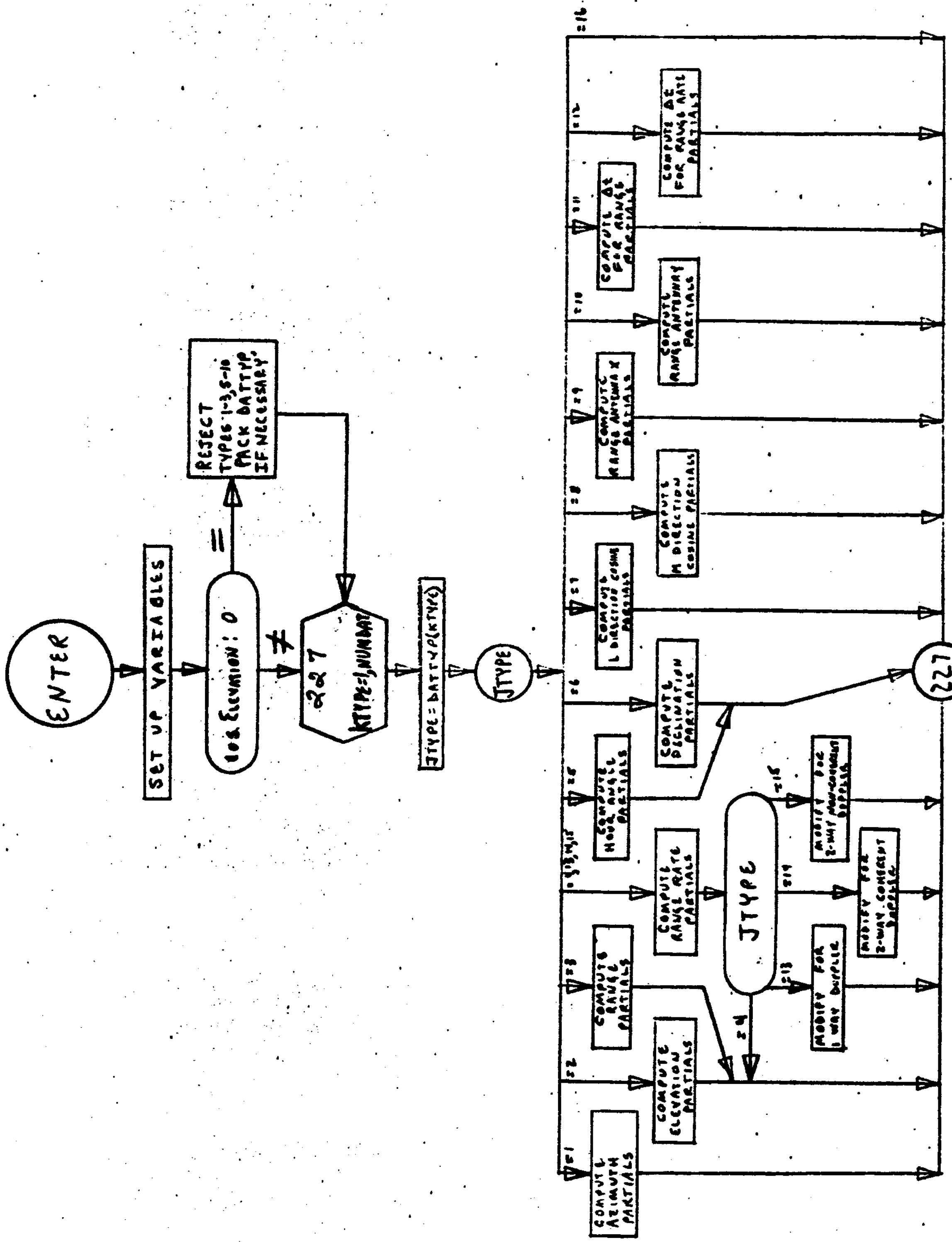
M - index of data type

NUMDTT - saved NUMDAT

56.6 Equations Used

See Ref. 1, Section 6.3

56.7 FLOW DIAGRAM - PTLSB1



57. Subroutine REWIN

This is a dummy subroutine which will cause the system to rewind the overlay tape. It is called by the Minimum Variance statistical program when it is a print time with no observations. When there are observations, the observation programs will automatically rewind the tape.

58. Subroutine SBSRB1

This subroutine computes the ground station observations. It is included in the link for Least Squares statistical processing.

This subroutine is an exact duplicate of OBSRB1 (for a complete writeup, see 49.   ), and has been put in due to the overlay structure.

SBSRB1 is called by:

BAYSB1

59. Subroutine SNOBS

This subroutine computes the on-board observations in the Least Squares statistical processing link.

The subroutine is an exact duplicate of ONOBS (for a complete writeup see 50.   ), and has been put in due to the overlay structure.

This subroutine is called by:

BAYSB1

60. Subroutine SNPTL

This subroutine computes the on-board partials of the observations with respect to the vehicle position and velocity. It is included in the link for Least Squares statistical processing.

This subroutine is an exact duplicate of ONPTL (for a complete writeup, see 51.), and has been put in due to the overlay structure.

SNPTL is called by:

BAYSB1

61. Subroutine STATB1

61.1 Purpose

This subroutine provides the major logic for solution of the orbit determination problem by the use of the minimum variance method.

61.2 Method

This subroutine provides the logic for accruing information at a data point. The covariance matrix before processing of the data is updated between points in MAINB1. Other logic is provided for the miss coefficient and propagation of error modes.

See Section 2.0 of this manual for a description of the flow between the MAINB1, STATB1, SUMARY and EXECB1 routines.

61.3 Program References

61.3.1 STATB1 is called by:

MAINB1

61.3.2 STATB1 calls:

DALFA, DMTML, DOMUD, MATINV, OBSRB1, ONOBS, ONPT2, PASMB1, PRNTB1, PTLSB1, REWIN, SYMMAT

61.4 I/O Data

61.4.1 Inputs from COMMON

ALAM1, DELX, DELY, EBAR, QSAVE, SAVEL1, SMAT, STAT, YOBS, YOBSNU
DATTYP, EBRVAL, IMODE, IPS, IQZERO, IRDATA, IRT, ISUMRY, KSTA, M6, MFLAG, MINUS1, MPLUS1, MPLUS2, MPLUS3, MPLUS4, NUMDAT, ONE, PASS, PAST, PSPACE, REJCT1, REJCT2, USETYP

61.4.2 Outputs to COMMON

DELALP, DELX, DELY, EBAR, STAT
AREJ, BMAT, EBRVAL, ITERS, KOMP, KTAB, NUMDAT, NUT

61.4.3 Other Inputs

None

61.4.4 Other Outputs

61.4.4.1 Rejection Information - print on L.T.3

II, BMAT (II, 1), YCOM (II), DELY (N)

where II is the number of the observation type

and N is the index for the packed DELY

61.4.4.2 Summary tape information - binary on L.T. 10

T, KSTA, ICOUNT, (BMAT (I, 2), I = 1, 25) (BMAT (I, 1), I = 1, 25), AREJ

61.5 Symbols Used

61.5.1 COMMON Symbols

ALAM1, ALMAT, SAVEL1, SMAT

61.5.2 Other Symbols

AMINV1 - BCD word = STTB1A

AMINV2 - BCD word = STTB1B

FSGM - current multiplier for determining variance level above which data is to be rejected.

II - flag

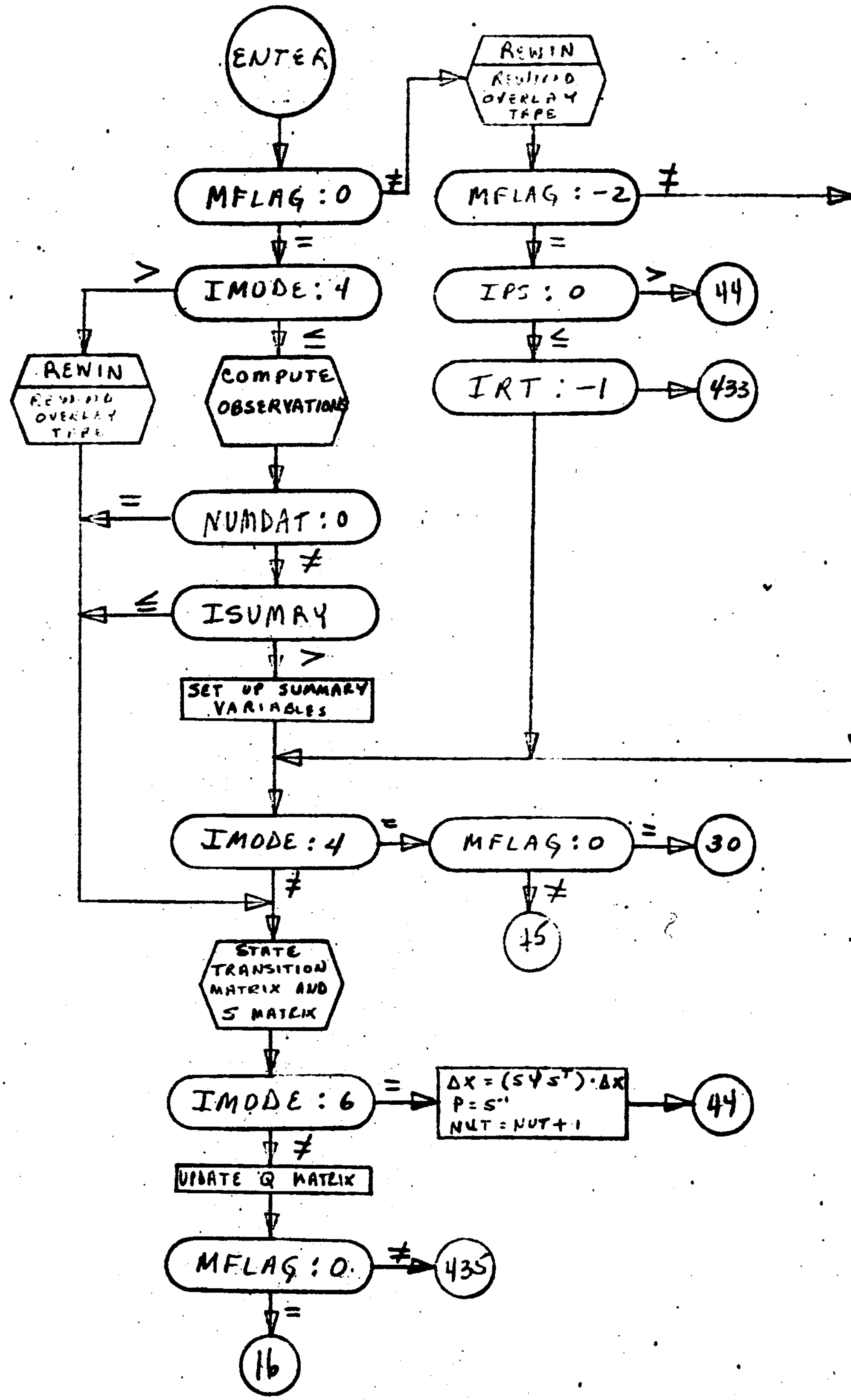
N - index

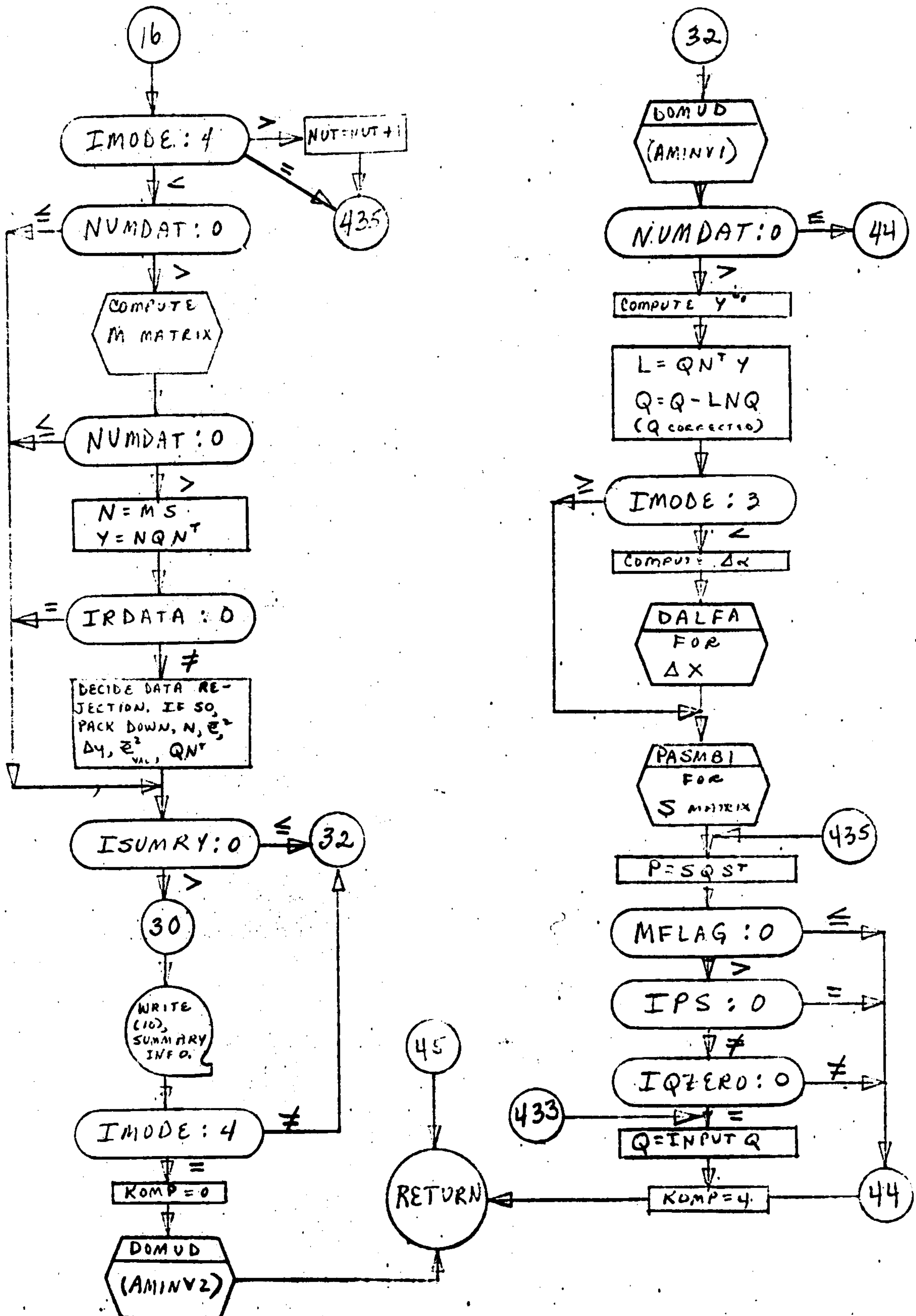
NUMDTT - saved value of NUMDAT

61.6 Equations Used

See Ref. 1, Section 5

61.7 Flow Diagram - STATB1




16
IMODE : 4
NUT=NUT+1
435
NUMDAT : 0
COMPUTE M MATRIX
NUMDAT : 0
N = MS
Y = NQN^T
IRDATA : 0
DECIDE DATA REJECTION. IF SO, PACK DOWN, N, ε², Δy, ε²VAL, QN^T
ISUMRY : 0
32
30
WRITE (10), SUMMARY INFO.
IMODE : 4
KOMP = 0
DOMUD
(AMINV2)
45
RETURN
32
DOMUD
(AMINV1)
NUMDAT : 0
44
COMPUTE Y
L = QN^T Y
Q = Q - LNQ
(Q CORRECTED)
IMODE : 3
COMPUTE Δα
DALFA
FOR
ΔX
PASMB1
FOR
S MATRIX
435
P = SQS^T
MFLAG : 0
IPS : 0
IQZERO : 0
433
Q = INPUT Q
KOMP = 4
44

62. Subroutine STISB1

This subroutine computes the ground station partials of the observations with respect to the vehicle position and velocity. It is included in the link for Least Squares statistical processing.

This subroutine is an exact duplicate of PTISB1 (for a complete writeup, see 56.   ), and has been put in due to the overlay structure.

STISB1 is called by:

BAYSB1

63. Subroutine SUMARY(KTAB)

63.1 Purpose

This subroutine reads in the summary tape and prints information out in the proper format.

63.2 Method

The tape is read in 6 times to check for each of the following types:

1. X, Y, Range, Range rate.
2. Right ascension, Declination, l and m direction cosines.
3. Azimuth, Elevation, Range equivalent, Range rate equivalent.
4. One-way doppler, Two-way coherent doppler, Two-way pseudo doppler.
5. Range angle, Planet-to-planet angle, Star-to-planet angle.
6. Star-to-landmark angle, Landmark-to-landmark angle, Occultation.

Each of these types is printed out in proper units and format with 57 lines on each page.

63.3 Program References

SUMARY is called by:

B1 - EXECB1
B2 - B2EXEC

63.4 I/O Data

63.4.1 Inputs from logical tape 10.

T - double precision time of data point

KSTA - station at which the observation is made

ICOUNT - correct number of the data point on the tape

SCOM - the 25 computed observations

SOBS - the 25 observed values

AREJ - 25 BCD words for whether pt. has been rejected

63.4.2 Outputs

TEMP1(25) - root mean square of each type

63.4.3 Other Inputs

KTAB - the total number of data points on the tape

63.5 Symbols Used

IA - index for first data observation in a group

IB - index for second data observation in a group

IC - index for third data observation in a group

ID - index for fourth data observation in a group

IKTAB - flag for titles

INCT - indicator for a new page within a group

IRTB - indicator for which group is being considered.

J - index

NLINE - counter for lines on a page

PAST - BCD word = * - for checking AREJ array

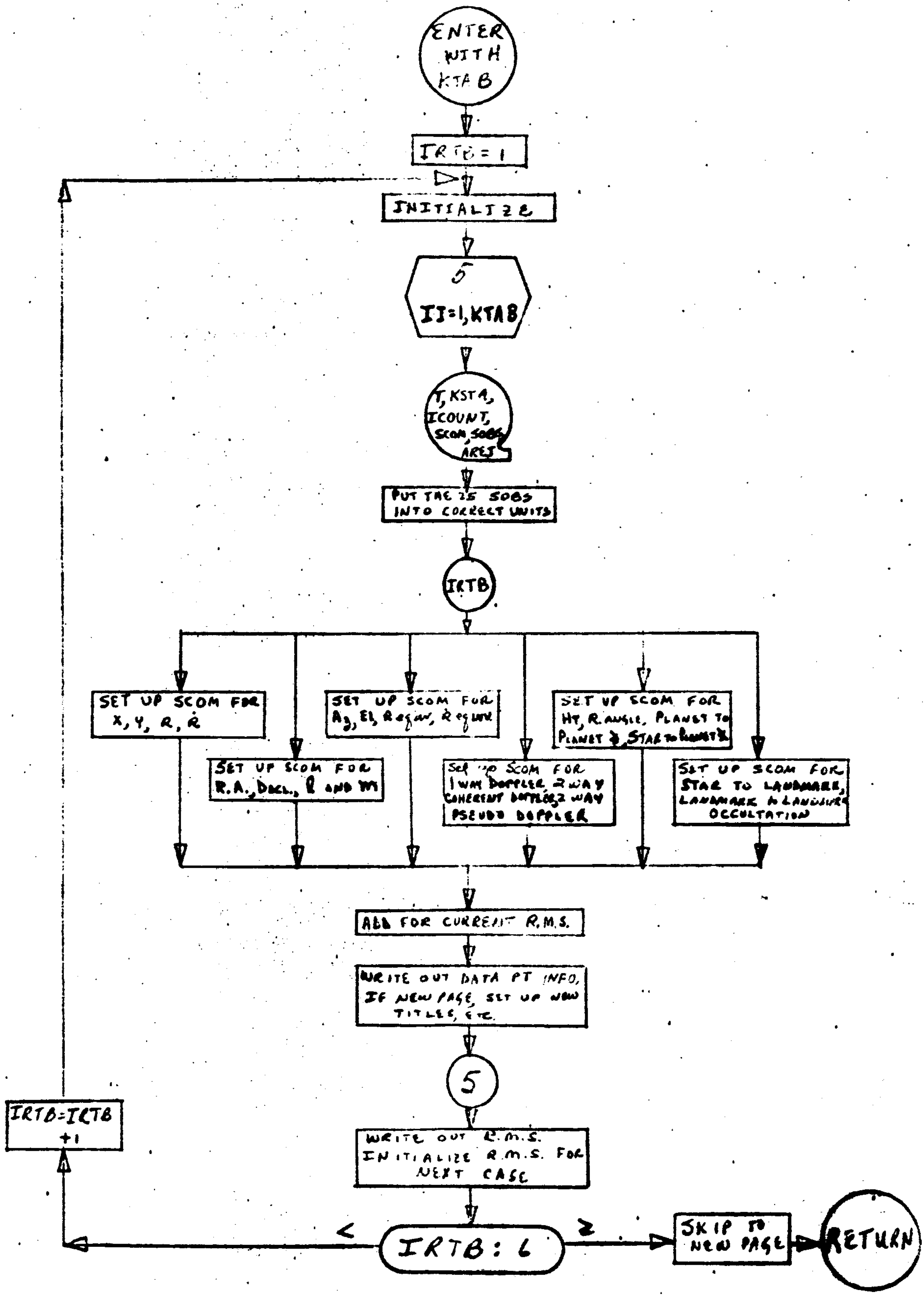
RACON - conversion factor

SUM - summation to check for printing

TEMP2(25) - summation of number of points in a type

63.6 Equations Used

None


ENTER WITH KTAB
IRTB = 1
INITIALIZE
5
II=1,KTAB
T, KSTA, ICOUNT, SCOM, SOBS, ARES
PUT THE 25 SOBS INTO CORRECT UNITS
IRTB
SET UP SCOM FOR X, Y, R, Ṙ
SET UP SCOM FOR R.A., DECL., ℓ AND m
SET UP SCOM FOR Az, El, Rrange, Ṙrange
SET UP SCOM FOR 1 WAY DOPPLER 2 WAY COHERENT DOPPLER 2 WAY PSEUDO DOPPLER
SET UP SCOM FOR Ht, R.ANGLE, PLANET TO PLANET ∡, STAR TO PLANET ∡
SET UP SCOM FOR STAR TO LANDMARK, LANDMARK TO LANDMARK OCCULTATION
ADD FOR CURRENT R.M.S.
WRITE OUT DATA PT INFO, IF NEW PAGE, SET UP NEW TITLES, ETC.
5
WRITE OUT R.M.S. INITIALIZE R.M.S. FOR NEXT CASE
IRTB=IRTB +1
<
IRTB : 6
≥
SKIP TO NEW PAGE
RETURN

64. Subroutine SYMMAT(A,N,M)

64.1 Purpose

This subroutine symmetrizes a matrix A.

64.2 Method

See "Equations Used".

63.3 Program References

SYMMAT is called by:

B1 - BAYSB1, STATB1
B2 - BYSB2, STTB2

64.4 I/O Data

64.4.1 Inputs

A - matrix to be symmetrized

N - actual square dimension of A

M - square dimension of A to be symmetrized

64.4.2 Outputs

A - the input matrix symmetrized

64.5 Symbols Used

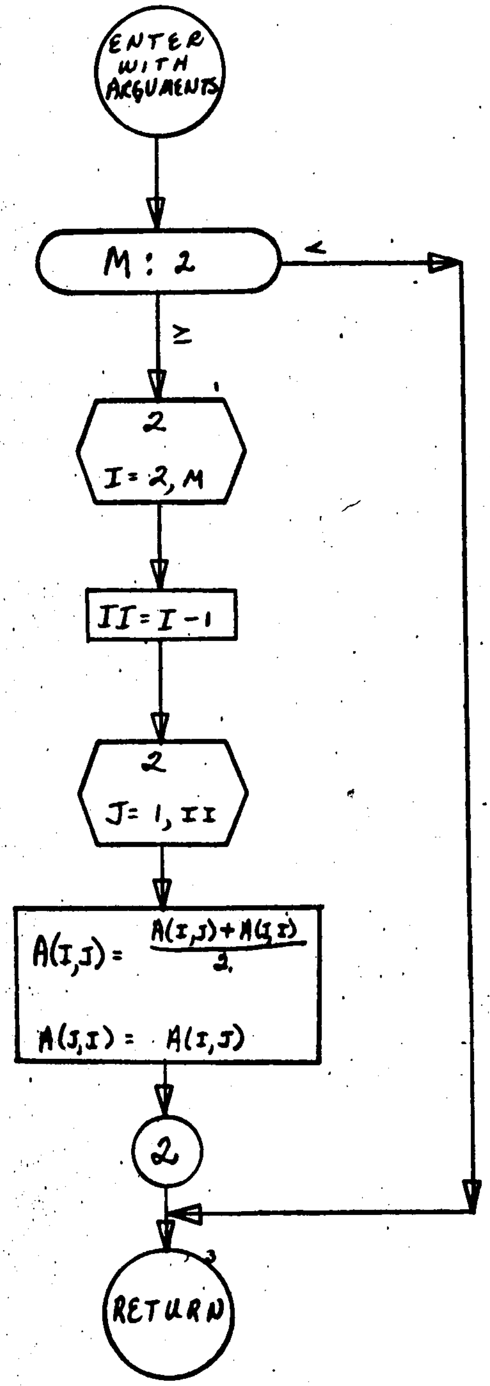
None

64.6 Equations Used

$$A_{ij} = \frac{A_{ij} + A_{ji}}{2}$$

$$A_{ji} = A_{ij}$$

64.7 FLOW DIAGRAM - SYMMAT



65. Subroutine B2BOB

This subroutine is essentially the same as subroutine ONOBS(50.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) It is used in the Least Squares link (see SNOBS(59).).

b) B2BOB is called by

BYSB2

c) B2BOB calls

STPSB2 rather than STAPOS.

66. Subroutine B2BTLS

This subroutine is essentially the same as subroutine CNPTL(51.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) It is used in the Least Squares link.

b) Equations used for computing the partials are different in form but equivalent in content.

c) Variable B2ONP - BCD word = BPTLS.

67. Subroutine B2EPHM

This subroutine is essentially the same as subroutine EPHEM (22.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) it is called by CBCHRF, CB2DER, EBCHRF, EB2DER, B2OCUL

b) the variables TPMT11, and TABLE are contained in the BLOCK COMMON - EPHEM

68. B2EXEC

68.1 Purpose

This is the executive program for the B2 mode.

68.2 Method

Logic is included in the routine for controlling the calls to B2MAIN, SUMARY and B2INPT. The logic includes control of both the BAYES and STAT statistical routines especially when a summary is requested.

68.3 Program References

B2EXEC calls:

B2INPT, B2MAIN, SUMARY

68.4 I/O Data

68.4.1 Inputs from COMMON

AMUD, FIRST, INPERR, ISTAT, ISUMRY, KLAST, KTAB, MPLUS1, NOFT, NT

68.4.2 Outputs to COMMON

FIRST, IXADD (11), NT

68.4.3 Other Inputs and Outputs

None

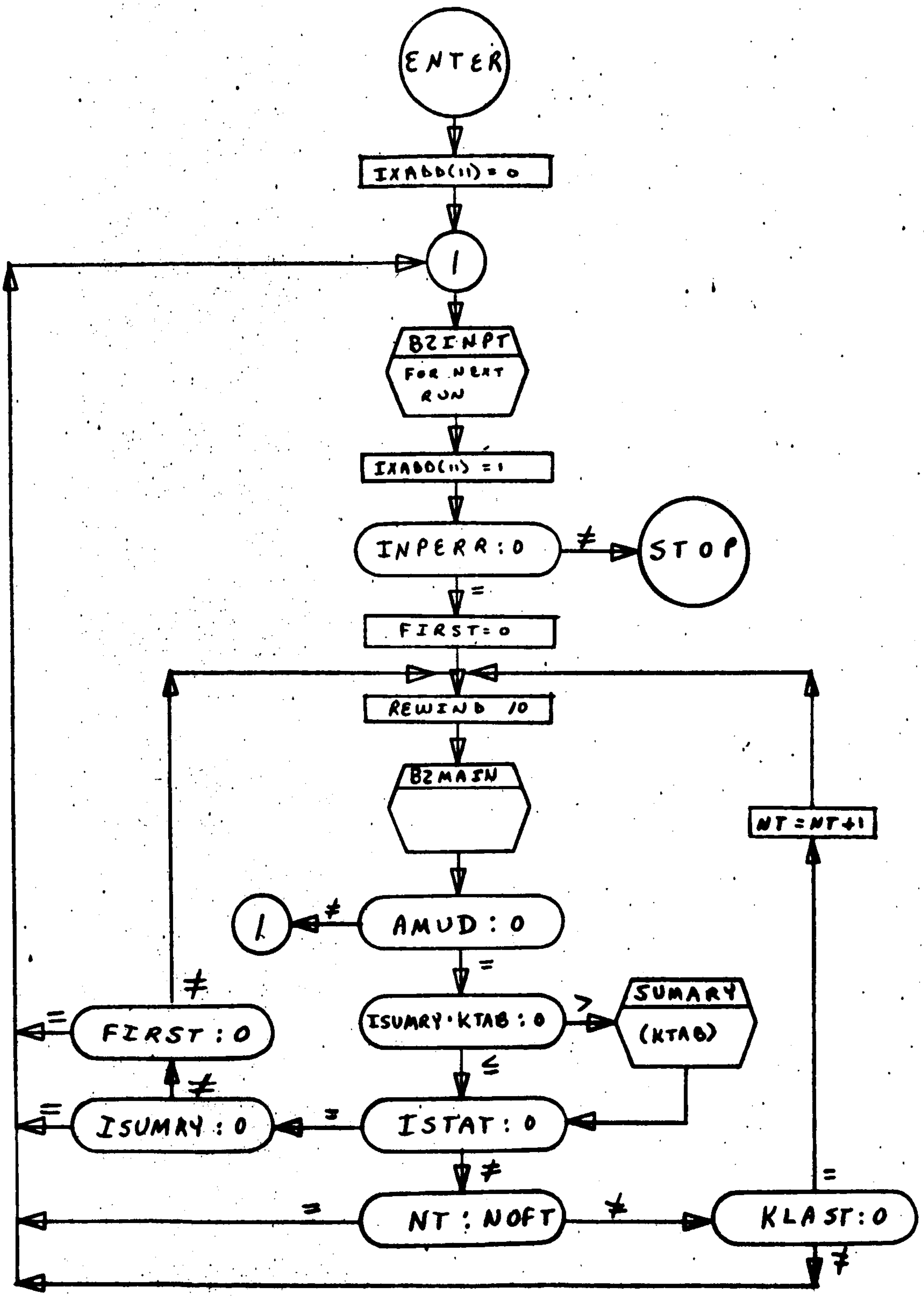
68.5 Symbols Used

None

68.6 Equations Used

None

68.7 Flow Diagram - B2EXEC



69. Subroutine B2INPT

69.1 Purpose

This subroutine reads in all data necessary for one run.

69.2 Method

The subroutine initializes necessary data and reads in sections desired. Depending on the input quantity KSTDRD, certain variables are either read in or set up to nominal values within the program.

Due to the shortage of core storage, the array STAT(26,26) is placed in a labelled COMMON block and used in a lower programming link. Communication between Input and statistics is therefore attained by use of tape 11. For stacked cases, after the first entry to B2INPT, the program reads in STAT from the tape.

69.3 Program References

69.3.1 B2INPT is called by:

B2EXEC

69.3.2 B2INPT calls

B2PASM, DMTML, DMUDB2, FIX, MATINV, SERVCE, XFRMB2

69.4 I/O Data

69.4.1 Inputs from COMMON

IXADD(11) - used for reading the matrix STAT from logical tape 11

69.4.2 Outputs to COMMON

INPERR

plus all initialised and inputted data

69.4.3 Other Inputs

69.4.3.1 For a complete listing of the data deck, see Ref. 2, Section 2.3

69.4.3.2 The matrix Q is read from logical tape 11 in modes 1, 2, and 3 from the previous run, (depending on IXADD(11)).

(STAT(I,J), J = 1, NBST) - NBST records

69.4.4 Other Outputs

69.4.4.1 A printout is made of all input quantities

69.4.4.2 The matrix Q (Q^{-1} in Least Squares Mode) is written on logical tape 11 in modes 1, 2, and 3

(STAT(I,J), J = 1, NBST) - NBST records

69.5 Symbols Used

69.5.1 COMMON Symbols

TPMAT4, TPMAT8, TPMAT9

69.5.2 Other Symbols

DYNARR(60) - (Data) - nominal values of dynamic states

SCAL(3,7) - (Data) - the matrix from which the array SCALE is chosen, depending on IUNIT

TZ - time from start of launch day

ALPHA(3,7) - (Data) - matrix from which the array PVALPH is chosen, depending on IUNIT

CDN(40) - (Data) - standard coefficient of drag table, from which CDT is set up

DAYN - number of days from January 1, 1960 to start of launch year

ICMN - index for correct C_{mn} in the DYN array

IGGSD - initial guess for random number generator

IPR(8) - (Data) - array of alphameric titles

IR - index to tell how many records to skip in order to bring Ephemeris tape up to current time

IR2 - temporary variable for printout of input

ISMN - index for correct S_{mn} in the DYN array

ITITLE(12) - Array read in for title of run

IW - temporary variable for printout of input

PASTD - data word for setting PAST

PSPACD - data word for setting PSPACE

RECT1 - BCD word = RECT1

XMACHN(40) - (Data) - standard Mach number tables from which XMACH is set up

69.6 Equations Used

When P matrix is read in, transformation to the Q matrix is as follows:

$$Q = S^{-1} P(S^{-1})^T$$

69.7 Flow Diagram

See INPUTA(26.7)

70. Subroutine B2KEP

This subroutine is essentially the same as subroutine KEPLER (27.).

The difference, which arises from the fact that it is used in a different program, is that it is called by EB2DER.

71A. <u>Subroutine B2 MAIN</u>

This subroutine controls the flow between the integration and Minimum Variance statistical portions of the program. Its flow is essentially the same as that for subroutine MAINB1, following the Minimum Variance blocks, with the exception that

a) No powered flight is included

b) Due to bias error inclusion, matrix manipulation is done by partitioning (see page 12).

71B. Subroutine B2MAIN

This subroutine controls the flow between the integration and Bayes Least Squares statistical portions of the program. Its flow is essentially the same as that for subroutine MAINB1, following the Least Squares blocks, with the exception that:

a) No powered flight is included

b) The procedure for writing a truncated data set on tape 11 is:

```
     WRITE (11) T,RC,RDC,MWREF
        DO 300 I=1,6
     WRITE (11) (SMAT(I,J),J=1,6)
300  WRITE (11) (SAVEL2(I,J),J=1,  NDSVB
```

c) The procedure for writing a complete data set on tape 11 is:

```
     WRITE(11) T,RC,RDC,MWREF,ICOUNT,LTEMP,LTEMP1,
               IPLNT,TKRAW,DATA
        DO 301 I=1,6
     WRITE (11) (SMAT(I,J),J=1,6),CPOS(I,IPLNT),
               CVEL(I,IPLNT)
301  WRITE (11) (SAVEL2(I,J),J=1,NDSVB)
```

d) Due to bias error inclusion, matrix manipulation is done by partitioning (see page 12).

72. Subroutine B2NUT(K)

This subroutine is essentially the same as subroutine NUTPRE(30).

The differences, which arise from the fact that it is used in a different program mode, are:

B2NUT is called by

CBMNOB rather than CMNOBP

CBOBDG rather than COBDRG

EBMNOB rather than EMNOBP

EBOBDG rather than EOBDRG

STPSB2 rather than STAPOS

B2MAIN - both versions

73. Subroutine B2OBOS

This subroutine is essentially the same as subroutine ONOBS(50.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) B2OBOS is called by

   STTB2

b) B2OBOS calls

   STPSB2 rather than STAPOS

74. Subroutine B2OCUL

This subroutine is essentially the same as subroutine STACUL(38.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) B2OCUL is called by

B2MAIN (both versions)

b) B2OCUL calls

B2EPHM rather than EPHEM

B2KEP rather than KEPLER

75. Subroutine B2ONPL

This subroutine is essentially the same as subroutine ONPTL(51.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) Equations used for computing the partials are different in form but equivalent in content.

b) Variable B2ONP - BCD word = B2ONPL.

76. Subroutine B2PASM(IFLAG)

76.1 Purpose

This subroutine computes the S, S^{-1} or State Transition Matrix depending on IFLAG.

76.2 Method

When IFLAG = 1, compute S in SMAT

When IFLAG = 2, compute S^{-1} in SMAT

When IFLAG = 3, compute State Transition Matrix

- Upper left 6 x 6 - in ALAM1
- Upper right 6 x (NDB) in ALAM2 (packed)

If KOMP = 4, ALAM1 = I, ALAM2 = 0

In Bayes statistics, when KOMP = 0, the State Transition Matrix is stored in SMAT (6,6) and SAVEL2(6,NDB). It is the accumulated matrix from time 0, rather than from the last data point as done in Minimum Variance.

76.3 Program References

76.3.1 B2PASM is called by:

B2INPT, BYSB2, STTB2

76.3.2 B2PASM calls:

DDOT, DMTML, DMUDB2, SERVCE

76.4 I/O DATA

76.4.1 Inputs from COMMON

ALMAT, BETA, DYN, EF1, EF2, EF6, EF7, HMU, RA, RC, RDC, RDI, RDTB, RI, RTB, SAVEL2, SQTMU, T, TBF, TBFD, TBG, TBGD, TI, XFAC
ISTAT, KOMP, M6, M20, M26, MCOL, MPLUS1, MPLUS3, MPLUS4, MWREF, NCSB, NDB, NDSVB, OFFSET, ONE, THREE, TWO

76.4.2 Outputs to COMMON

ALAM1, ALAM2, RDTB, RTB, SMAT

76.4.3 Other Inputs

IFLAG

76.4.4 Other Outputs

None

76.5 Symbols Used

76.5.1 COMMON Symbols

SAVEL1, SAVEL2, TPMAT4, TPMAT5, TPMAT6, TPMAT8, TYMAT9

76.5.2 Other Symbols

IMATCH - Index of current column being computed in ALAM2

INDEX - Column number of first dynamic bias

PART1 - BCD word = B2PASM

SMAT1 - BCD word = SMATB2

76.6 Equations Used

76.6.1 See Ref. 1, Section 5

76.6.2 ALAM2 (1,J) is the partial of X with respect to the J-th dynamic bias considered. In program symbols, it is given by

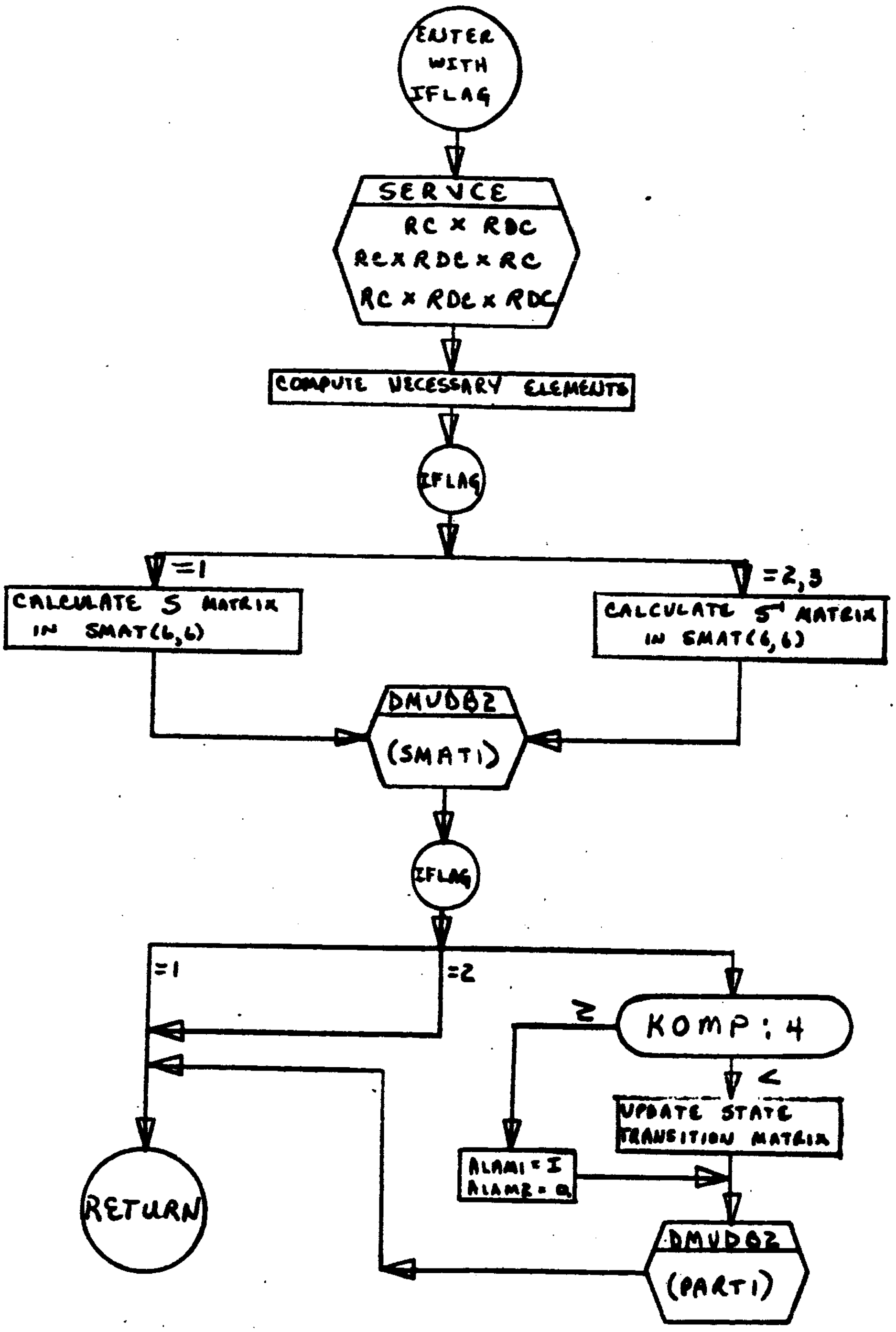
$$\frac{\text{CWLLN (1, J + 1) - CWLIN (1,1)}}{\text{Offset (J)}}$$

76.6.3 When the bias type being considered is the gravitational constant of the reference body, the column of ALAM2 corresponding to this bias is

position elements - $\dfrac{R_{TB}(T) - \dot{R}_i(I) \cdot (T - TI) - R_i(I)}{DYN(MWREF + 39)}$

velocity elements - $\dfrac{\dot{R}_{TB}(I) - \dot{R}_i(I)}{DYN(MWREF + 39)}$

76.6 FLOW DIAGRAM - B2PASM



77. Subroutine B2PLST

77.1 Purpose

This subroutine computes the ground station partials of the observations with respect to the vehicle position and velocity and the off-nominal states. It is included in the link for Least Squares statistical processing.

77.2 Method

The program first checks to see whether any further rejection is necessary. It then proceeds to compute the appropriate partials of the first type, storing them by columns in row 1 of SAVEL2. If there are additional data types, they are computed and stored in succeeding rows, up to a maximum of 4.

77.3 Program References

77.3.1 B2PLST is called by:

BYSB2

77.3.2 B2PLST calls:

DDOT, DMTML, DMUDB2

77.4 I/O Data

77.4.1 Inputs from COMMON

COMB, FRQ, GAM, GHA, HMU, OBSPLS, ORM, OVB, RC, RCMSC, RDC, STAC, STAOR, WE, XNCY, YCOM, YOBS, YOBSNU
AREJ, DATTYP, FUP, KM, KSTA, M6, M26, MCOL, MPLUS1, MPLUS3, MPLUS4, NBST, NCDST, NCMB1, NCOMB, NCSB, NSB, NUMDAT, ONE, PSPACE, TWO

77.4.2 Outputs to COMMON

DELY, EBAR, SAVEL2
AREJ, DATTYP, EBRVAL, NUMDAT

77.4.3 Other Inputs and Outputs

None

77.5 Symbols Used

77.5.1 COMMON Symbols

TPMAT1, TPMAT2, TPMAT4, TPMAT5, TPMAT6, TPMAT7, TPMAT8, TPMAT9

77.5.2 Other Symbols

CA, CB, CD, CE, CG, CX - cosine variables

CMAG - magnitude of position vector from center of earth to station

DXDA - temporary variable

RRS - temporary variable

SA, SB, SE, SEA, SECA, SECE, SG, SX, SXCX - trigonometric variables

TE, TNH2, TORM, TPHI, TRRS - temporary variables

TERMM - the current partial

VALC1, VALC2, VALDT, VALPD, VALPR, VALPRR, VALT7, VDA, VDE - coefficients used in computing partial

BTL1 - BCD word = B2PLST

I6, ICODE, ISWTCH, NCODE - flags for current bias type

ICOL - current column number

IROW - current row number

JTYPE- current data type being processed

KX - saved NUMDAT

NUMCD - index

M - index of data type

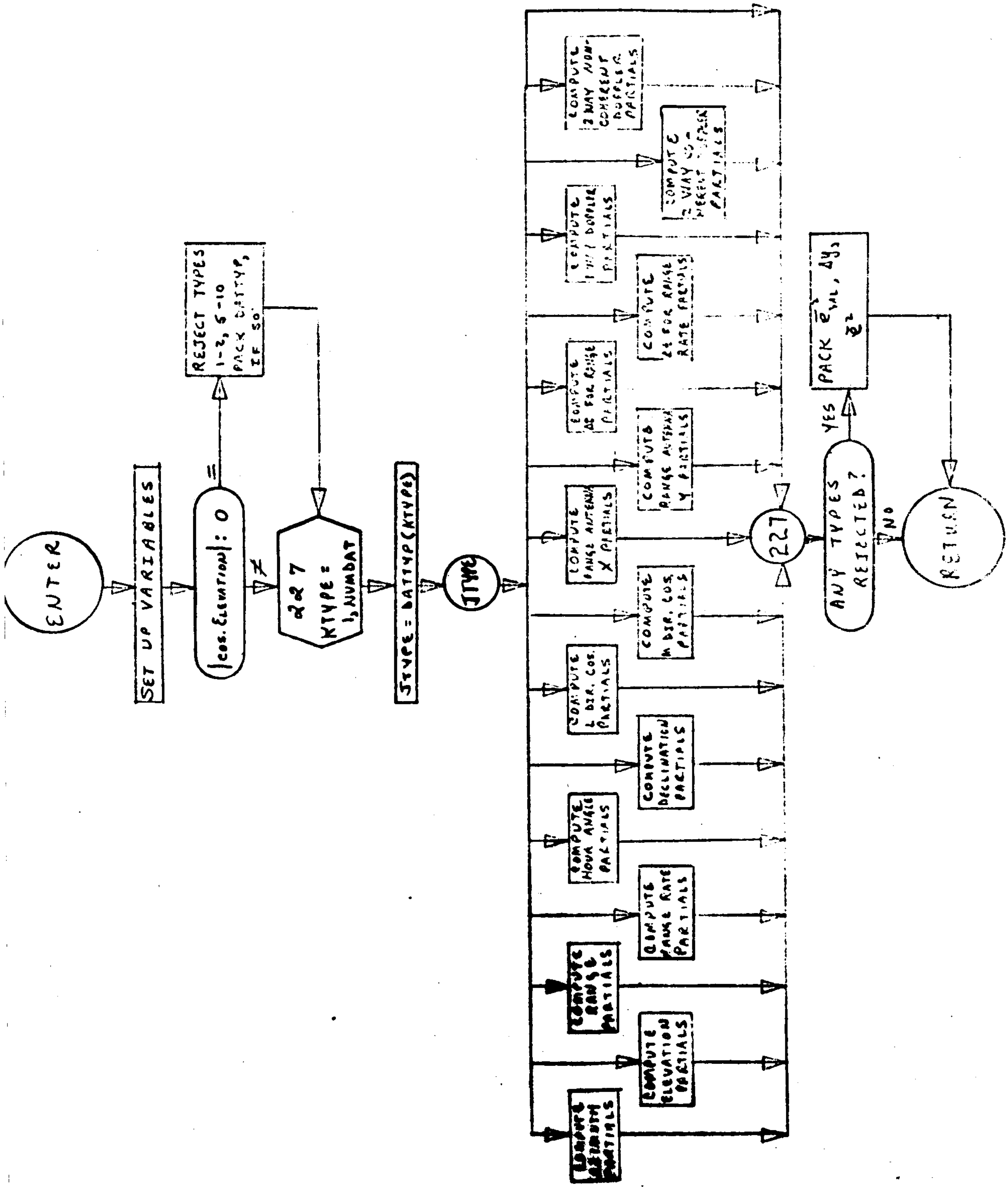
NUMDTT - saved NUMDAT

PASTD - BCD word = $

77.6 Equations Used

See Ref. 1, Section 6.3

77.7 FLOW DIAGRAM - B2DIST



78. Subroutine B2RECT

This subroutine is essentially the same as subroutine RECT (35).

The differences, which arise from the fact that it is used in a different program mode, are:

a) CWLIN is not in BLANK COMMON in the B2 mode. It is initialized elsewhere.

b) B2RECT is called by
B2MAIN, EBITG

79. Subroutine B2STOB

This subroutine is essentially the same as subroutine OBSRB1(49.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) It is used in the Bayes Least Squares link.

b) Refraction biases are included.

The 6 nominal refraction states (STAOR) are stored in T1 (1-6).

The nominal case is computed first, then each of the biases.

b.1) COMMON Variables added

DELP, KCOM, M5, MCOL, NCOMB, NSB, PARTD, PARTR, PARTRR

b.2) Other Variables

IC - index for bias type for ICP

ICP(6) - flag for refraction biases = 0, no bias
= 1, want bias

KKT - counter of which bias being considered

KT - flag for whether the nominal or a bias is being considered

c) B2STOB is called by

BYSB2

d) B2STOB calls

MDLB2 rather than MODELA

STPSB2 rather than STAPOS.

80. Subroutine BPRA2 (NON)

This program is essentially the same as subroutine PBIA (53.). The only difference, which arises from the fact that it is used in a different program mode, is that it calls BPTA2 rather than PTB1.

81. Subroutine BPRB(KOOK)

81.1 Purpose

The subroutine prints out statistical information.

81.2 Method

After determining that it is a print time from KPRINT, the subroutine checks KSECPR(KOPT, KOOK). If the value is non-zero, the corresponding section is printed.

81.3 Program References

BPRB is called by:

BYSB2, STTB2

81.4 I/O Data

81.4.1 Inputs from COMMON

ALAM1, ALAM2, ALMAT, CONST, DELALP, DELX, DELY, EBAR, SAVEL2, SCALE, SMAT, STAC, STAT, T, YCOM, YOBS
DATTYP, ILUNE, IPLNT, ISTAR, KOPT, KPRINT, KSECPR, KSTA, MFLAG, NBST, NDB, NDSVB, NUMDAT, PVALPH, SPADD(8), STANM

81.4.2 Outputs to COMMON

None

81.4.3 Other Inputs

KOOK

81.4.4 Other Outputs

See Ref. 2, Section 3.3.2.

81.5 Symbols Used

81.5.1 COMMON Symbols

TPMAT4, TPMAT5

81.5.2 Other Symbols

DATYPE(4) - packed OBTYPE array

KJP - flag for on-board type

NP1 - star number for printout (on-board system)

NP2 - station number for printout (on-board system)

OBTYPE(25) - BCD data array for the 25 types

OBUNIT(25) - BCD data array for the units of each of the 25 types

81.6 Equations Used

None

81.7 Flow Diagram

See PRNTB1(54.7).

82. Subroutine BPTA2

This subroutine is essentially the same as subroutine PTB1 (55.).

The only difference (in the write-up), which arises from the fact that it is used in a different program mode, is that it is called by BPRA2 rather than PB1A.

83. Subroutine BPTLS

This subroutine computes the ground station partials of the observations with respect to the vehicle position and velocity and the off-nominal states. It is included in the link for Minimum Variance statistical processing.

This subroutine is an exact duplicate of subroutine B2PLST(77.), and has been put in due to the overlay structure.

BPTLS is called by:

STTB2

84. Subroutine BYSB2

This subroutine is essentially the same as subroutine BAYSB1(42).

The differences, which arise from the fact that it is used in a different program mode, are:

a) bias errors are included in the calculations. Therefore, the variables defining these are needed as inputs to the program. Upon completion of the program, new nominals are stored in their respective locations of the COMB, STAOR and/or DYN arrays.

b) BYSB2 is called by

B2MAIN

c) BYSB2 calls

DLFB2 rather than DALFA

B2PASM rather than PASMB1

BPRA2 rather than PB1A

BPRB rather than PRNTB1

B2STOB rather than SBSRB1

B2BOB rather than SNOBS

B2PLST rather than STLSB1

B2BTLS rather than SNPTL

d) The first record of the nominal tape, for both Preconvergence and Post Convergence Modes is read and written as:

(STAT(I,J), J = 1, NBST) - NBST TIMES

e) The complete data set in the Preconvergence Mode is:

e.1) T, RC, RDC, MWREF, ICOUNT, LTEMP, LTEMP1, IPLNT, TKRAW, DATA

e.2) (ALAM1(I,J), J = 1,6), CPOS(I,IPLNT), CVEL(I,IPLNT)

e.3) (ALAM2(I,J), J = 1, NDSVB)
e.2 and e.3 are written and read in a DO loop for I = 1,6

f) The truncated data set in the Post Convergence Mode is read as:

f.1) T, RC, RDC, MWREF

f.2) (ALAM1(I,J), J = 1,6)

f.3) (ALAM2(I,J), J = 1, NDSVB)
f.2 and f.3 are read in a DO loop for I = 1,6.

85. Subroutine CB2DER

This subroutine is essentially the same as subroutine CDERIV(3).

The differences, which arise from the fact that it is used in a different program mode, are:

a. CB2DER is called by:

   CBNT

b. CB2DER calls

B2EPHM	rather	than	EPHEM
CBMNOB	"	"	CMNOBP
CBMVDG	"	"	CMVDRG
CBOBDG	"	"	COBDRG

c. When computing off-nominal accelerations (KCOM>1), the gravitational constant is saved and offset by the corresponding variable input array OFFSET. The acceleration terms are stored in the BLOCK COMMON /CBD/ variable RAT(3,2,1) rather than RDDOT.

d. The following additional COMMON variables are used:

   OFFSET - the values of the dynamic biases to be offset
   KCOM - the indicator of the set of accelerations being considered
   MCOL - input array of code words of bias types
   NSB, NCOMB - number of station-oriented and combination-type biases, respectively
   NCODE - index of the gravitational constant being considered

e. The following additional internal variables are used:

   SVST - saved gravitational constant

   INN - index of which bias in the MCOL array

f. No powered flight accelerations are included.

86. Subroutine CBCHRF

This subroutine is essentially the same as subroutine CCHREF (2.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) CBCHRF is called by CBITG

b) CBCHRF calls B2EPHM rather than EPHEM.

87. Subroutine CBITG

This subroutine is essentially the same as subroutine CITGRA (6.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) no powered flight is used

b) the Variable PURP is eliminated

(In flow chart follow path for PURP = 1)

c) LML does not exist in B2 mode

88. Subroutine CBMNOB

This subroutine is essentially the same as subroutine CMNOBP (7.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) CBMNOB is called by CB2DER

b) CBMNOB calls B2NUT rather than NUTPRE.

89. Subroutine CBMVDG

This subroutine is essentially the same as subroutine CMVDRG (8.).

The difference, which arises from the fact that it is used in a different program mode, is that it is called by CB2DER.

90. Subroutine CBNT(IENT)

90.1 Purpose

This subroutine is the Cowell integrator. Runge-Kutta integration is used for short time integration and to start the Nordsieck long time integration.

90.2 Method

The method is the same as for subroutine CINT(4.2) with the exception that besides computing the nominal position and velocity vectors, it also computes those for each of the dynamic biases and stores them in ALMAT for use by the statistical portion of the program.

90.3 Program References

90.3.1 CBNT is called by

CBITG

90.3.2 CBNT calls

CB2DER

90.4 I/O Data

90.4.1 Inputs from COMMON

DTI, OLDT, RAT, RC, RDC, T
IP, MPLUS1, MPLUS2, MPLUS4, NDB1, ONE, RTO, THREE

90.4.2 Outputs to COMMON

ALMAT, RC, RDC, T
IP, KOOM

90.4.3 Other Inputs

IENT

90.4.4 Other Outputs

None

90.5 Symbols Used

90.5.1 COMMON Symbols

SAVEL2, TPMAT5

90.5.2 Other Symbols

BRG(6,6,21) - adjusted values of velocity and acceleration of last six integration steps for nominal and dynamic bias states.

H, RKA, RKB, RKC, RKFT, RKT, XK - see CINT (4.5)

BET, BETT, COEF, CT1, IGT, KE, KI - see CINT (4.5)

90.6 Equations Used

Runge-Kutta Gill method of integration

Nordsieck method of integration

See Ref. 1, Section 3.2.3

90.7 Flow Diagram

See CINT (4.7).

91. Subroutine CBOBDG

This subroutine is essentially the same as subroutine COBDRG.

The differences, which arise from the fact that it is used in a different program mode, are:

a) CBOBDG is called by CB2DER

b) CBOBDG calls B2NUT rather than NUTPRE

92. Subroutine DLFB2

This subroutine is essentially the same as subroutine DALFA (43.).

The only difference (in the write-up), which arises from the fact that it is used in a different program mode, is that it is called by BYSB2 and STTB2.

93. Subroutine DMUDB2 (TEST)

This subroutine is essentially the same as Subroutine DOMUD (13.).

The only difference, which arises from the fact that it is used in a different program mode, is that it is called by many of the B2 mode subroutines.

94. Subroutine EB2DER

This subroutine is essentially the same as subroutine EDERIV(15). The differences which arise from the fact that it is used in a different program mode, are:

a. Powered flight is not considered.

b. EB2DER is called by:

   EBNT

c. EB2DER calls

B2EPHM	rather	than	EPHEM
B2KEP	"	"	KEPLER
EBMNOB	"	"	EMNOBP
EBMVDG	"	"	EMVDRG
EBOBDG	"	"	EOBDRG

d. When computing off-nominal perturbations (KCOM > 1), the gravitational constant is saved and offset by the corresponding value in the input array OFFSET. The perturbation terms are stored in the BLOCK COMMON /D1/ variable CWLIN(9,21) rather than CWLIN(9).

e. The following additional COMMON variables are used.

   OFFSET - the values of the dynamic biases to be offset
   KCOM - the indicator of the set of perturbations
   MCOL - input array of code words of bias types
   NSB, NCOMB - number of station-oriented and combination type biases, respectively
   NCODE - index of gravitational constant being considered.

f. The following additional internal variables are used:

   SVST - saved gravitational constant

   INN - index of which bias in MCOL array

95. Subroutine EBCHRF

This subroutine is essentially the same as subroutine ECHREF (14.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) EBCHRF is called by
   EBITG

b) EBCHRF calls
   B2EPHM rather than EPHEM, and
   B2KEP rather than KEPLER

96. Subroutine EBITG

96.1 Purpose

This subroutine serves as the sub-main program governing calls to the integration subroutines in the Encke method.

96.2 Method

The program checks to see whether to change reference. Depending on position, the deltas of integration and printing are determined, and integration is performed up to T_{p} .

96.3 Program References

96.3.1 EBITG is called by:

B2MAIN

96.3.2 EBITG calls:

B2KEP, B2RECT, EBCHRF, EBNT

96.4 I/O Data

96.4.1 Inputs from COMMON

DT, DT3, OLDT, PRNT3, R1, R2, RC, RDTB, RT1, RT2, RTB, T, TD
CNT, CWLIN, FPK, IDER, IP, IXADD (13), KOMP, KS2BY, KSPLT, MPLUS1, MPLUS2, MPLUS3, MWREF, ONE, RTO, THREE

96.4.2 Outputs to COMMON

DELTP, DTI, OLDT, RC, RDC, SAVD, T, TD
CNT, IDER, IP, KOMP, KSTA

96.4.3 Other Inputs and Outputs

None

96.5 Symbols Used

See CITGRA (6.).

96.6 Equations Used

None

96.7 Flow Diagram

See EITGRA (18.7) for PURP = 1 and no powered flight test.

97. Subroutine EBMNOB

This subroutine is essentially the same as subroutine CMNOBP (7 .).

The differences, which arise from the fact that it is used in a different program mode, are:

a) EBMNOB is called by
   EB2DER

b) EBMNOB calls B2NUT rather than NUTPRE

98. Subroutine EBMVDG

This subroutine is essentially the same as subroutine EMVDRG (20.).

The difference, which arises from the fact that it is used in a different program mode is that it is called by EB2DER.

99. Subroutine EBNT(IENT)

99.1 Purpose

This subroutine is the Encke integrator. Runge-Kutta integration is used for short time integration and to start the Nordsieck long time integration.

99.2 Method

The method is the same as for subroutine EINT(16.2) with the exception that besides computing the perturbations of the nominal position and velocity vectors, it also computes those for each of the dynamic bias states and stores all these vectors in ALMAT for use by the statistical portion of the program.

99.3 Program References

99.3.1 EBNT is called by:

EBITG

99.3.2 EBNT calls:

EB2DER

99.4 I/O Data

99.4.1 Inputs from COMMON

DTI, OLDT, RC, RDC, T
CWLIN, IP, MPLUS1, MPLUS2, MPLUS4, NDB1, ONE, RTO, THREE

99.4.2 Outputs to COMMON

ALMAT, RC, RDC, T
IP, KCOM

99.4.3 Other Inputs

IENT - see CINT(4.2)

99.4.4 Other Inputs

None

99.5 Symbols Used

99.5.1 COMMON Symbols

SAVEL2
BMAT

99.5.2 Other Symbols

H, RKA, RKB, RKC - see CINT(4.5)

BRG(6,6,21) - adjusted values of perturbations of velocity and acceleration of last 6 integration steps for nominal and dynamic bias states

BET, BETT, COEF, CT1, IGT, KB, KI, RKFT, RKT, XK - see CINT(4.5)

99.6 Equations Used

Runge-Kutta-Gill method of integration

Nordsieck method of integration

See Ref. 1, Section 3.2.3

99.7 Flow Diagram

See CINT(4.7)

100. Subroutine EBOBDG

This subroutine is essentially the same as COBDRG (9.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) EBOBDG is called by

EB2DER

b) EBOBDG calls

B2NUT rather than NUTPRE

EINTRP rather than CINTRP

101. Subroutine MDLB2 (K)

This subroutine is essentially the same as MODELA (29). The only difference, which arises from the fact that there may be a refraction bias measurement, is that instead of using the STAOR array, a temporary array T1 (dimensioned by 6) is used which has been set up in the calling program.

102. Subroutine OBBSR

This subroutine is essentially the same as subroutine OBSRB1(49.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) Refraction biases are included.

The 6 nominal refraction states (STAOR) are stored in the array T1. The nominal case is computed first, then each of the biases.

a.1) COMMON Variables added

DELP, KCOM, M5, MCOL, NCOMB, NSB, PARTD, PARTR, PARTRR

a.2) Other Variables

IC - index of bias type for ICP

ICP(6) - flag for each bias = 0, no bias
= 1, want bias

KKT - counter of which bias being considered

KT - flag for whether the nominal or a bias is being considered.

b) OBBSR is called by

STTB2

c) OBBSR calls

MDLB2 rather than MODELA

STPSB2 rather than STAPOS

103. Subroutine STPSB2

This subroutine is essentially the same as subroutine STAPOS(39.).

The differences, which arise from the fact that it is used in a different program mode, are:

a) STPSB2 is called by

B2STOB, CBBSR

b) STPSB2 calls

B2NUT rather than NUTPRE.

104. Subroutine STTB2

104.1 Purpose

This subroutine is the main program for the Minimum Variance statistical link.

104.2 Method

The subroutine provides the logic for accruing information at a data point. The covariance (Q) matrix before processing of the data is updated between points in B2MAIN. Other logic is provided for the Miss Coefficient and Propagation of Error modes.

Due to the shortage of core storage, the Q matrix (STAT(26,26)) was put in labelled COMMON/ CSTAT/ in a lower link. In order to communicate between this program and Input, the matrix was stored on logical tape 11.

Two Q matrices are saved on this tape - the inputted Q and the grown Q. When beginning a new PASS, the inputted quantity IQZERO is checked. If the inputted Q is desired, that Q is placed as the second Q.

Upon exit from the program the tape is positioned at the beginning of the second Q matrix.

See Section 2.0 of this manual for a description of the flow between the MAIN, STAT, SUMARY and EXEC routines.

104.3 Program References

104.3.1 STTB2 is called by:

B2MAIN (Minimum Variance)

104.3.2 STTB2 calls:

B2OBOS, B2ONPL, B2PASM, BPRB, BPTLS, DLFB2, DMTML, DMUDB2, MATINV, OBBSR, REWIN, SYMMAT

104.4 I/O Data

104.4.1 Inputs from [illegible]

ALAM1, ALAM2, [illegible], [illegible], [illegible], [illegible]2, SMAT, YOBS
DATTYP, EBRVAL, IMODE, IPS, IQZERO, IRDATA, ISUMRY, KSTA, M5, M6, M26, MCOL, MFLAG, MPLUS1, MPLUS2, MPLUS3, MPLUS4, NCOMB, NCSB, NDB, NDB1, NDSVB, NSB, NUMDAT, ONE, PASS, PAST, PSPACE, REJCT1, REJCT2

104.4.2 Outputs to COMMON

COMB, DELALP, DELX, DYN, EBAR, QSAVE, STAOR, STATE
AREJ, EBRVAL, ITERS, KCMP, KTAB, NUMDAT, NUT

104.4.3 Other Inputs

The Q matrix is read in from logical tape 11.

(STAT(1,J), J = 1, NBST) - NBST Records

104.4.4 Other Outputs

104.4.4.1 The Q matrix is again written out. Logical tape 11 contains, on the first NBST records, the value of Q_o. The second NBST records contain the updated Q. When beginning a new pass, the inputted quantity IQZERO is tested to determine whether the new Q matrix will be the inputted Q or the grown Q. This Q is written on the second NBST records. The tape is then positioned at the beginning of the second set.

104.4.4.2 Rejection information - on L.T. 3

II, BMAT(II,1), YCOM(II), DELY(N)

where II is the number of the observation type

BMAT is the single-precision computed observation (YCOM)

and N is the index for the packed DELY

104.4.4.3 Summary tape information - binary on L.T. 10

T, KSTA, ICOUNT, (BMAT(I,2), I = 1,25), (BMAT(I,1), I = 1,25), AREJ

104.5 Symbols Used

104.5.1 COMMON Symbols

ALAM1, ALAM2, ALMAT, SAVEL1, SAVEL2, SMAT, TPMAT4
BMAT, KCOM

104.5.2 Other Symbols

AMINV1 - BCD word = STTB2A

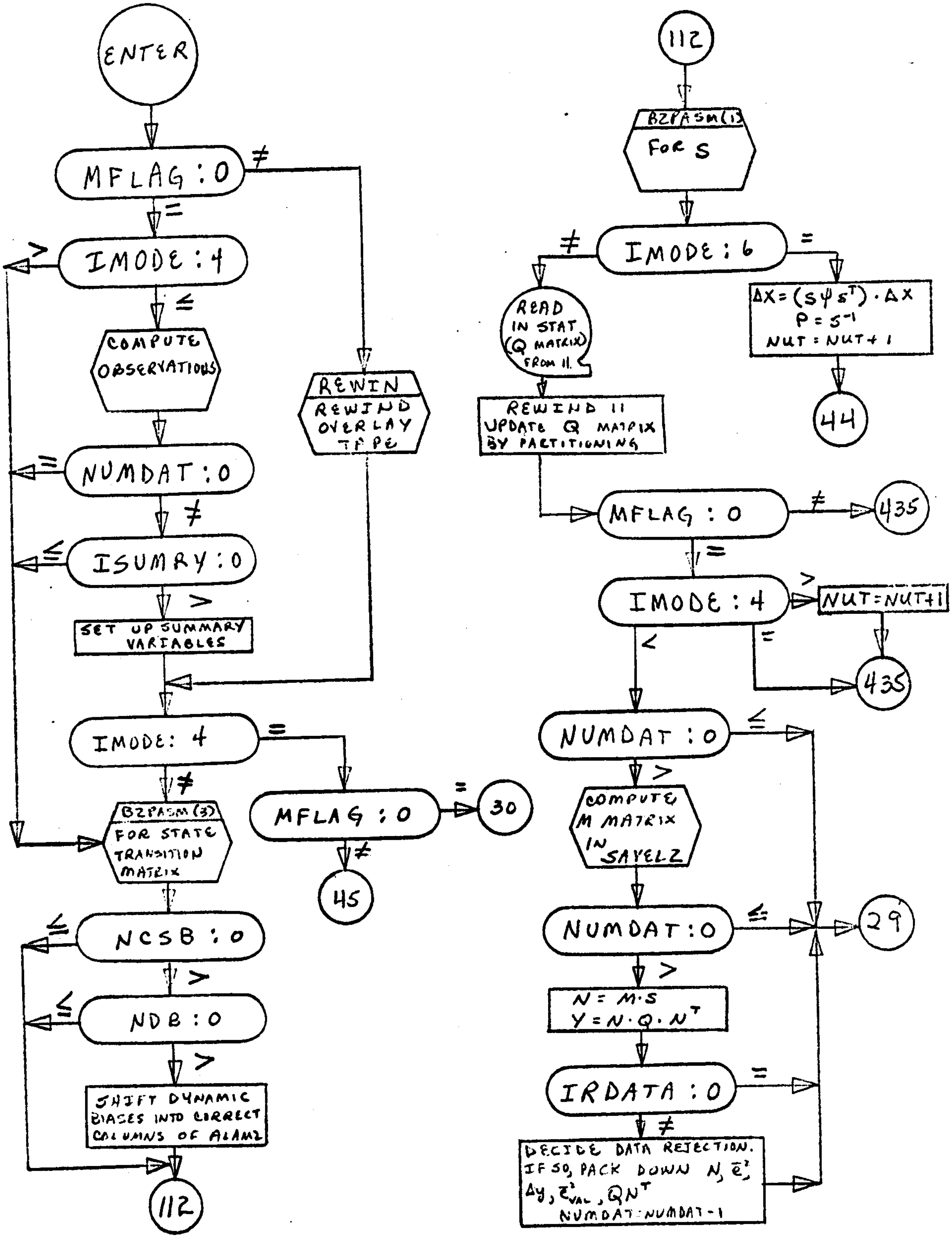
AMINV2 - BCD word = STTB2B

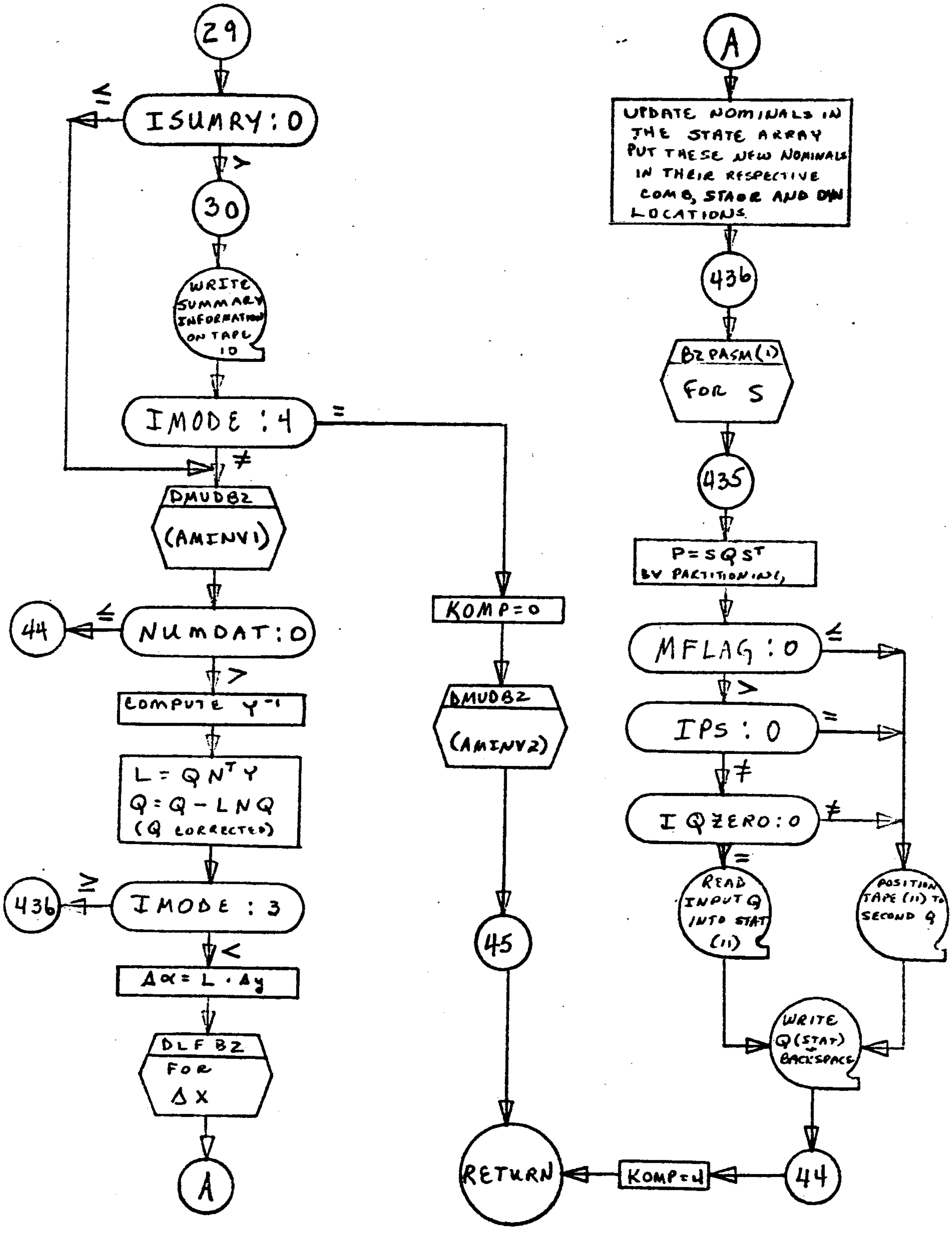
FSGM - current multiplier for determining variance level above which data is to be rejected

NUMDTT - saved NUMDAT

104.6 Equations Used

See Ref. 1, Section 5.


ENTER
MFLAG : 0
IMODE : 4
COMPUTE OBSERVATIONS
NUMDAT : 0
ISUMRY : 0
SET UP SUMMARY VARIABLES
REWIN
REWIND OVERLAY TAPE
IMODE: 4
MFLAG : 0
30
45
BZPASM (3)
FOR STATE TRANSITION MATRIX
NCSB : 0
NDB : 0
SHIFT DYNAMIC BIASES INTO CORRECT COLUMNS OF ALAM2
112
112
BZPASM(1)
FOR S
IMODE : 6
READ IN STAT (Q MATRIX) FROM 11
REWIND 11
UPDATE Q MATRIX BY PARTITIONING
ΔX = (SψS^T) · ΔX
P = S^-1
NUT = NUT + 1
44
MFLAG : 0
435
IMODE : 4
NUT=NUT+1
435
NUMDAT : 0
COMPUTE M MATRIX IN SAVEL2
NUMDAT : 0
29
N = M·S
Y = N·Q·N^T
IRDATA : 0
DECIDE DATA REJECTION.
IF SO, PACK DOWN N, ē², Δy, ε²VAL, QN^T
NUMDAT=NUMDAT-1


29
ISUMRY : 0
≤
>
30
WRITE SUMMARY INFORMATION ON TAPE 10
IMODE : 4
=
≠
DMUDBZ
(AMINV1)
44
NUMDAT : 0
COMPUTE Y⁻¹
L = QNᵀY
Q = Q − LNQ
(Q CORRECTED)
436
≥
IMODE : 3
<
Δα = L · Δy
DLFBZ
FOR
ΔX
A
KOMP=0
DMUDBZ
(AMINV2)
45
RETURN
A
UPDATE NOMINALS IN THE STATE ARRAY
PUT THESE NEW NOMINALS IN THEIR RESPECTIVE COMB, STABR AND DYN LOCATIONS
436
BZPASM(1)
FOR S
435
P = SQSᵀ
BY PARTITIONING
MFLAG : 0
IPS : 0
IQZERO : 0
READ INPUT Q INTO STAT (11)
POSITION TAPE (11) TO SECOND Q
WRITE Q(STAT) BACKSPACE
44
KOMP=4

105. Subroutine XFRMB2

This subroutine is essentially the same as subroutine XFORM(41.).

The difference, which arises from the fact that it is used in a different program mode, is that it is called by B2INPT.